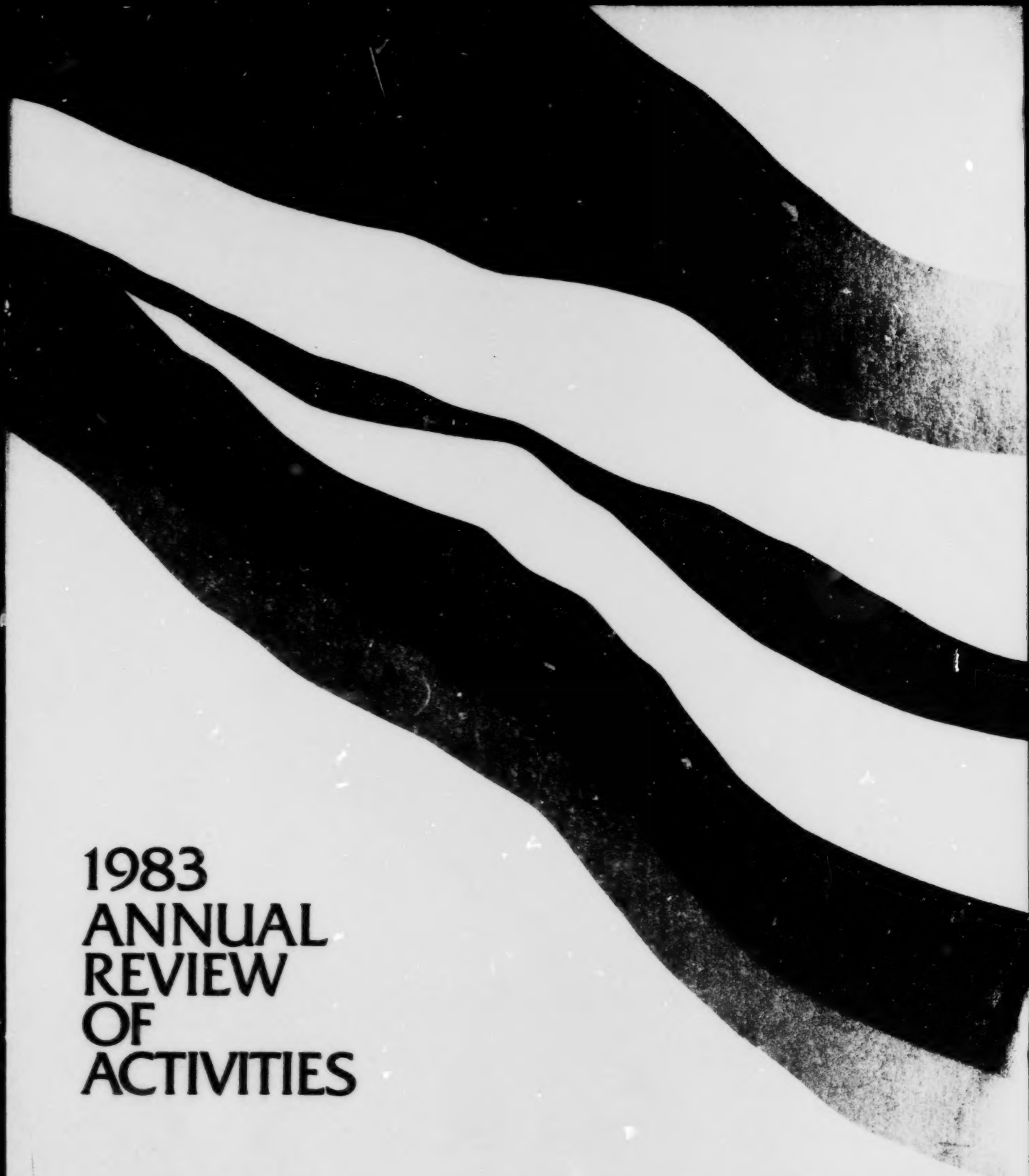


# 1983 ANNUAL REVIEW OF ACTIVITIES

Institute of Ocean Sciences

# 1983 ANNUAL REVIEW OF ACTIVITIES

Institute
of
Ocean Sciences

*Institute of Ocean Sciences with the Marine Technology Centre in the background.*

# 1983 ANNUAL REVIEW OF ACTIVITIES

## Institute of Ocean Sciences

PATRICIA BAY, SIDNEY, B.C.

Government of Canada Gouvernement du Canada

Fs 1-26/1983E

ISBN 0-662-13163-0

For additional copies or further information, please write to:

Department of Fisheries and Oceans
Institute of Ocean Sciences
P.O. Box 6000
Sidney, British Columbia, Canada
V8L 4B2

# Contents


DEPARTMENT OF FISHERIES AND OCEANS 7
Director-General's Foreword 9
Hydrography 11
Field Hydrography 13
Chart Production and Distribution 16
Tidal and Current Surveys 16
Engineering Services 19
Oceanography 23
Ocean Physics 25
Coastal Zone Oceanography 25
Frozen Sea Research 31
Offshore Oceanography 37
Forecast Methods 41
Remote Sensing 43
Computing Services 43
Ocean Chemistry 44
Ocean Ecology 50
Ocean Information 56
Ships 61
Management Services 65

DEPARTMENT OF THE ENVIRONMENT 69
Atmospheric Environment Service 71
Canadian Wildlife Service 73

DEPARTMENT OF ENERGY, MINES AND RESOURCES 75
Geological Survey of Canada & Earth Physics Branch 77
Director's Foreword 77
Sedimentology 78
Marine Geology and Geophysics of Georgia Strait 82
Palaeontology 85
Multiparameter Geophysical Surveys 86
Seismological Service 88
Gravity 91
Geothermal Studies 92
Geomagnetism 94

Arctic Structure and Tectonics 96
Geodynamics 96
Earth Physics Branch - Technical Support 97

APPENDICES
I. Contracts Awarded during 1983 99
II. Publications 103
III. Permanent Staff, 1983 115

# DEPARTMENT OF FISHERIES AND OCEANS

# Director-General's Foreword

In 1983 approval was obtained to proceed with the construction of a replacement vessel for the *Wm. J. Stewart*. The keel was laid at the Bel Aire shipyard in North Vancouver in January 1984 and the ship is expected to be completed by December 1984. The new ship, and the *Parizeau*, provide IOS with two ships capable of operating in the open ocean, one of which is capable of work in the Arctic as the new ship is ice strengthened. The impact of the program will be tremendous as it will give IOS the opportunity to plan offshore and arctic programs with the assurance that a ship will be available to carry them out. In the past we have had to rely on chartering a second ship or on *Hudson* coming around from the East coast. Either of these could only be arranged if the task was extremely urgent and short-lived.

Hydrography is a major beneficiary of the new ship as it is first of all designed as a replacement for the *Wm. J. Stewart* which undertook offshore surveying of the Pacific coast. When she was taken out of service any systematic surveying of the Pacific coast was abandoned, partly because of commitments in the Beaufort Sea, but largely because there was no ship available other than *Parizeau* and only limited time was available on her. With the new ship we will be able to resume our charting of offshore areas and also to continue with surveying in the western Arctic.

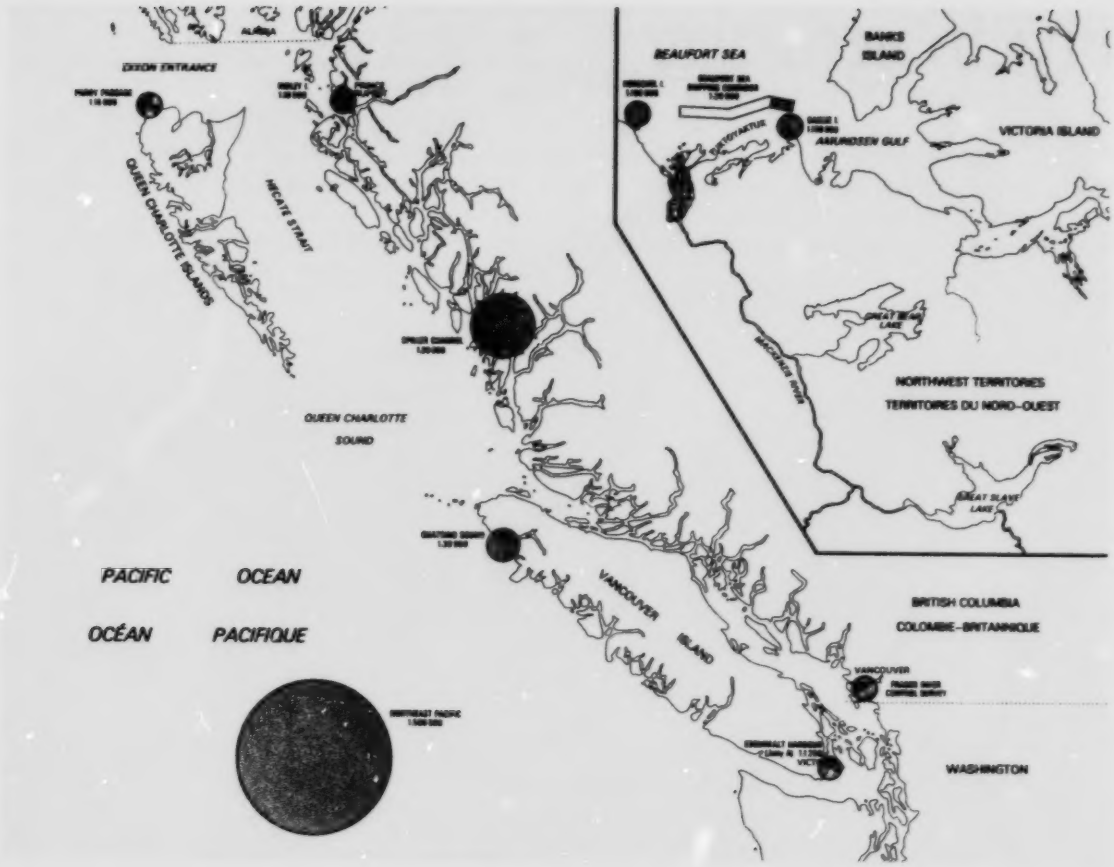
For oceanography sufficient ship time will be available to develop a Pacific-wide program in cooperation with other countries on the Pacific Rim. In the past the Pacific deep sea program was based on observations from the weatherships which provided an invaluable time series in waters adjacent to Canada. Following the withdrawal of the weatherships we attempted to continue the time series and our studies of waters adjacent to Canada but with only partial success owing to lack of ship time. Also it was only possible to send a ship to distant waters every 5-7 years, with no follow-up, so that no cohesive long term program could be thought of, let alone executed. Both these restrictions will be removed and we will be able to plan a deep sea program in Canadian and distant waters knowing that we will have sufficient ship time to implement them.

Another factor that is influencing the program is the acquisition of considerable sums of money, and a few person years, through the OERD program and the Transport R&D program, and it appears we will be funded through the NOGAP and Climate programs in the future. About one half of our operation O&M will come from these programs. The funds are tied to specific project objectives and they draw with them staff and funds from our A-Base so they are having a great influence on the direction of the IOS program. The objectives are specific, applied, and short term.

We will have to take some care that they do not pre-empt the longer term research and surveying that we support with our A-Base resources. So far, however, the acquisition of these funds has been beneficial as we have been able to design programs using a combination of A-Base and external resources that satisfy both objectives.

The disappointing aspect of the year's efforts is that I have been unsuccessful in making the point that IOS is a new institute with not enough staff to respond to the challenges of hydrography and oceanography in the Arctic and Pacific. It is my intention to continue to press the point as it is my conviction that it is reasonable, right, and will be recognized.

# Hydrography




*Pacific Region 1983 hydrographic survey program.*

# Hydrography

The main objective of the Hydrographic Division is to provide accurate, timely bathymetric and navigational information in the form of nautical charts, tide tables, current atlases and sailing directions for commercial and recreational users. Additional information is provided to other federal government agencies, engineering and consulting firms, universities, environmental groups and the general public.

This year saw the completion of surveys of the navigational corridor through the Beaufort Sea, in addition to new surveys and revisory surveys for the continuing charting program on the Pacific coast. A new tidal current atlas, covering the Juan de Fuca Strait and Strait of Georgia, was published and well received by the maritime community. Chart sales continued at a steady pace, consistent with previous years. Good progress was achieved in converting charts to the metric/bilingual format, and with the Loran-C latticing of west coast charts.

# Field Hydrography

The Field Hydrography Section is responsible for conducting hydrographic surveys of the B.C. coast, western Arctic and navigable inland waters in the Pacific Region in order to ensure that requirements for navigational information are met. Alterations of, and additions to traffic routes, types and sizes of vessels, harbours, bottom topography and coastlines—all require an ongoing and resurvey program.

The major coastal survey party was assigned to the barge *Pender* from April to October. A resurvey of the Spiller Channel, Bella Bella area of the coast, which included the previously unsurveyed inlets of Bullock and Briggs and Gunboat Passage Narrows was completed. *(Contact: G.E. Richardson.)*

M.V. *Polar Circle* commenced her season at the northwest point of the Queen Charlotte Islands to carry out a resurvey of Parry Passage. The Admiralty last carried out surveys here in the early 1900s. The ship completed this survey in late June and sailed for the western Arctic in early July. Passage to Tuktoyaktuk was slow due to bad ice conditions.

The survey of the Beaufort Sea deep-draught shipping corridor was completed as was a standard survey north of the Baillie Islands connecting the eastern Beaufort Sea and western Amundsen Gulf survey areas of earlier seasons. An early onset of ice precluded much work on a planned survey west of Herschel Island and the ship departed for Halifax the first week of September. *(Contact: A.R. Mortimer.)*

C.S.S. *Richardson* left IOS in late April and made passage to Winter Harbour to continue the surveys of the entrance of Quatsino Inlet commenced in 1982. This

survey was broken off at the end of June with about 80 shoal examinations remaining to be done.

The *Richardson* survey party then moved to Ridley Island (Prince Rupert), the site of a new grain and coal terminal. New surveys were required for new charting in the area prior to the arrival of the first deep-draught carriers. This survey was 95% completed by October when the party returned to base. The remaining area was completed in early December when the construction equipment was removed. Shallow coring was carried out in potential anchorage areas and the cores were passed to Pacific Geoscience Centre (PGC) for analysis. *(Contact: J.V. Crowley.)*

Several small local survey projects were carried out from IOS. These included Tsehum Harbour, Esquimalt Harbour, Bamfield, Fraser River and Vancouver Harbour. *(Contact: B.M. Lusk.)*

Three Unsolicited Proposals from the private sector were considered this past year. One dealt with the survey of artificial Arctic islands from a fixed wing aircraft. The investigator was successful and proved that these islands can be monitored effectively in this manner. *(Contact: J. Vosburgh.)* The second proposal is still in progress and deals with the automated plotting of contours. A final edition of this software will be delivered in March of 1984. *(Contact: J. Vosburgh.)* The third proposal deals with the digital transfer of information from aerial photographs to field survey sheets and at this time is being analyzed for compatibility with present methods. *(Contact: B.M. Lusk.)*

Surveys for chart and sailing directions revisions were carried out under contract.

A contract was awarded for horizontal control in the western Arctic between Herschel Island and the Yukon/Alaska boundary and was completed.

## Sailing Directions

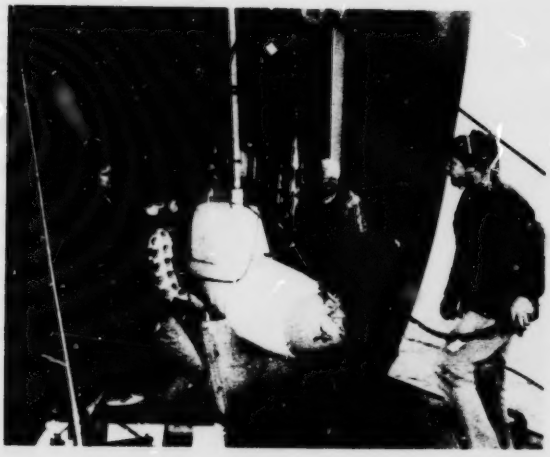
The Ninth Edition of the *British Columbia Coast Sailing Directions (North Portion), Volume II,* was published in May. This edition includes new information on tidal streams, seabed, vessel traffic services, Loran-C and port facilities. New photography and several new diagrams were incorporated into this edition. *Volume II* and *Volume I (South Portion)* are published in alternate years. *(Contact: Volume I, A. Smith; Volume II, J. Roberts.)*

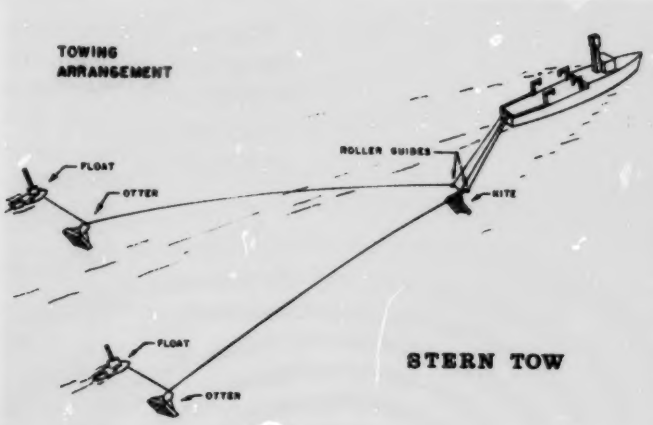
Due to marketing considerations, *Small Craft Guide, Volume I,* 6th Edition, was held back from a spring release until November. It will be back in phase for the 7th Edition. *(Contact: L.M. Wakefield.)*

Responsibility for the *Arctic Pilot, Volume III,* was transferred to Pacific Region in 1983.

## Hydrographic Development

A major project undertaken this year was the implementation of the Stern Tow sounding system to generate a greater volume of data for surveys such as the Beaufort Sea Corridor. Stern Tow was used and tested for a short period to improve the towing configuration. The Hydrographic Acquisition and Logging (HAL) data logger, an off-shoot of the Stern Tow, was built over the winter and used extensively in the Beaufort Sea. This new generation data logger, providing more, and better, data at greater frequency has necessitated new processing software.






*Deployment of the Stern Tow sounding system in the Beaufort Sea.*

The previously mentioned bathymetric contouring contract was also part of hydrographic development activities this year. The first two phases of this four phase project have now been completed, and preliminary plots have recently been presented for review.

Field evaluation of Sea Marc II was conducted, in conjunction with Engineering Services and PGC, off the west coast of Vancouver Island on a cruise on board the University of Hawaii's research vessel *Kana Keoki*. Conclusions are not yet available.

# ○○○○ Chart Production and Distribution

The functions of Chart Production and Distribution are to ensure that survey and other data are processed for publication as expeditiously as possible and to ensure that a ready supply is on hand for all users.

Twelve new standard charts were produced in Pacific Region this year in addition to 48 new editions and 13 reprints. A heavy load of hand amendments precipitated the preparation of 15 over-printings and 13 chart amendment patches were required. The Distribution Centre handled requests for 195,000 charts and 70,000 publications during the year.

Eighteen Notices to Shipping and 120 Notices to Mariners were issued, necessitating 160 chart amendment tracings, and 436 MAREP (the Canadian Power Squadron's Marine Reporting Program) reports were processed.

Four staff attended CARTO I, two senior staff attended the CARTO II training program and another participated in an exchange assignment with CHS' sister organization in the U.S., NOAA (National Oceanic and Atmospheric Administration).

A VAX-11/750 minicomputer system was delivered and the latter half of 1983 was spent converting software from the PDP-11/34. The system, providing much faster file processing and multiple simultaneous use, was tested successfully and will be integrated into the production routine early in 1984.

Promotional and educational activities continued with participation in two boat shows in B.C. and other activities such as tours and lectures. The new "Current Atlas: Juan de Fuca Strait to Strait of Georgia" was successfully launched at the Vancouver Boat Show and the initial printing subsequently sold-out before year's end.

The chart inventory and control system, initiated last year, was adapted to use six years of sales data as a base and is working well.

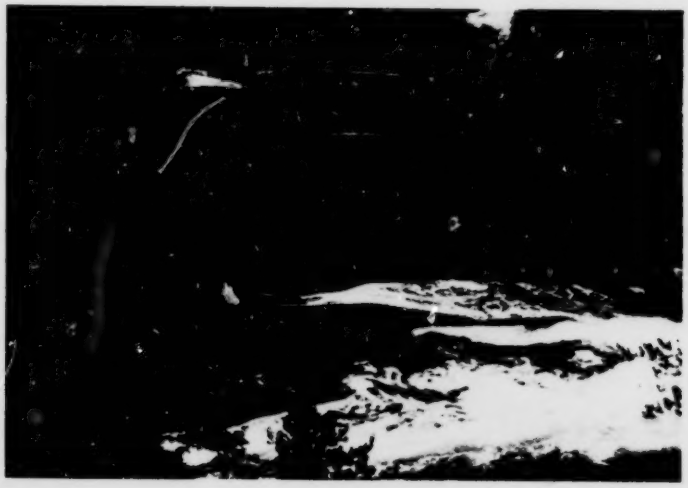
# ○○○○ Tidal and Current Surveys ○○○○

A study of the circulation in the waters surrounding the Queen Charlotte Islands, started in Queen Charlotte Sound in 1982, continued into Hecate Strait, and, in collaboration with Offshore Oceanography, into the area of the west coast of the Queen Charlotte Islands. Moorings of current meters and tide gauges will be serviced at four month intervals for two years.

Preliminary results from satellite-tracked drifters in these waters illustrate several of the important features of these basins. Waters in the central portion of Queen

Charlotte Sound do not appear to follow an average flow pattern, but exhibit a moving pattern of eddies. This was suspected from an analysis of current meter records from the 1982 survey and also is reflected on the drifter tracks. One of the drifters, released on September 9, 1983, was trapped in these gyres for over a month until a storm in late October carried it into Hecate Strait. It is suspected that the relatively narrow width of Hecate Strait prevents the formation of eddies and gyres, especially in late fall and winter during strong southeast winds. The drifter was carried along the Strait, across Dixon Entrance and into Clarence Strait in Alaska. Subsequently, its motion reversed; it was carried back into Dixon Entrance, where it remained for several weeks until it exited into the North Pacific, 80 days after release. Its track showed sustained uniform motion only in Hecate Strait. The irregular motion elsewhere will be studied in detail in future work. *(Contact: W.R. Crawford, W.S. Huggett.)*

Plans to gather additional data from drifters in Dixon Entrance proceeded by means of contract to develop and deploy Loran-C tracked drifters. These are to give frequent and accurate position, permitting the resolutions of tidal and inertial period motions.



*Measuring the current in Sechelt Rapids; here the current is flooding at 13 knots.*

A turbulence profiler to look at shallow water and continental shelf mixing processes was built according to existing designs and modified with a unique guard to enable employment closer to the bottom. This profiler was used, with success, on two separate cruises in Hecate Strait. *(Contact: W.R. Crawford.)*

In the Canadian Arctic, a multi-year program to increase knowledge of long-term mean sea level variations in waters contiguous to the Arctic archipelago was continued. Six water level recorders at permanent gauging sites in the western Arctic

were operated and a gauge at Baychimo was deployed for the purpose of determining mean sea level for the Geodetic Survey. *(Contact: F.E. Stephenson.)*

Four experimental current meters were deployed and recovered in Dease Strait. Unfortunately, data recovery was disappointing, but the difficulties with the instruments have been determined and are being resolved. *(Contact: M.J. Woodward.)*

Inspection, maintenance and operation of several temporary tide gauges and two Tsunami Warning gauges on the coast of British Columbia was carried out on a routine basis. Data from these gauges, as well as from 17 permanent tide gauges, are routinely sent to Marine Environmental Data Service (MEDS). Work has been carried out on the acquisition of two meteor-burst data transmitting systems, to relay data to the Institute from remote gauge locations. *(Contact: F.E. Stephenson.)*

Model studies of tides, currents and salinities in the Fraser River were continued. Numerous model runs were produced by request of various groups and agencies. Model runs of a prediction model for oil spill movement were made upon request. *(Contact: A.B. Ages.)*

Current surveys were carried out in Nakwakto Rapids and Sechelt Rapids in order to improve predictions in these fast-flowing narrows. The survey in Nakwakto Rapids will have to be repeated due to malfunctioning instruments. The survey in Sechelt Rapids was successful. *(Contact: M.J. Woodward.)*

## Tsunamis

The tsunami of May 26, 1983 in the Sea of Japan with the loss of 100 lives is once again a reminder of the threat these destructive waves pose to communities on the coasts of the Pacific Ocean. Recognizing that preparedness can save lives and reduce property damage, IOS participated with federal, provincial and municipal agencies in two exercises in 1983 to test the warning systems in B.C.'s coastal communities. Valuable lessons were learned, and tests may be conducted yearly.

Research continued on the historical knowledge of tsunamis that can be applied to hazard evaluation and mitigation. In cooperation with PGC, studies are in progress on the tsunami-generating potential of submarine landslides on delta fronts, with particular interest at this time in the Fraser Delta.

International cooperation has been extended in helping to improve the Tsunami Warning System in the Pacific. The Tsunami Warning Centre at Palmer Alaska assumed regional responsibility in 1983 for the Canadian west coast. *(Contact: S.O. Wigen.)*

## Diving Unit

Diving activity in 1983 remained at about the same level as in 1982. Approximately 100 dives were carried out, with the majority being to install or recover bottom-mounted pressure gauges. Major project areas this year were Alice Arm, Queen Charlotte Sound, Hecate Strait and the west coast of the Queen Charlotte Islands. Pressure gauges installed on either side of Sechelt Rapids and Nakwakto Rapids were also serviced several times during the year. Closer to home there was some activity at the CEPEX bag site and hull inspections for *Richardson*, *Pender* and *Vector* were carried out.

In the Arctic, both Frozen Sea Research Group and Tidal and Current Surveys benefitted tremendously from the use of commercial contract divers to recover water level gauges and current meters through the ice. *(Contact: F.E. Stephenson).*

*Recovering a tide gauge from the west side of the Arctic's Queen Elizabeth Islands.*

# Engineering Services

Engineering Services provides electronic and mechanical engineering, electronics support for hydrographic surveys, oceanographic research and ship operations, and an industrial liaison service promoting interaction between IOS, other government departments, and the private sector. *(Contact: T.A. Curran.)*

## Engineering Development

This group provides custom development of instrument systems, contract management of government-funded private sector developments, and ongoing electronic/mechanical consultations to all IOS groups.

Continued progress was made on the Active Drifter concept and prototype. A hull was constructed and field-tested in rough waters, and demonstrated good stability. Solar panels charging lead-acid batteries provided power. A Wagner autopilot was used to provide steering control. Work remains in the areas of power management and buoy positioning. It is hoped that commercial exploitation of the technology will occur.

A launch datalogger for hydrography was developed as a result of the Stern Tow project. It is continuing to receive software development support and a PILP (Program for Industry/Laboratory Projects) proposal has been prepared by a local company for NRC (National Research Council) funding to refine the system and to market it worldwide.

Other instrumentation projects included a beam attenuance meter for Ocean Ecology Division, a hand-held current meter for Tidal and Current Surveys and implementation of the SAIL system on the *Parizeau* and *Vector*.

Contract management is consuming a larger proportion of the group's time. The Correlation Sonar contract, phases III and IV, will result in acoustic remote sensing units which can produce a profile of current speed as a function of depth when located on the sea surface or the ocean bottom. Another contract will result in a novel pressure sensor using backscattered light into a laser diode cavity. Several tools of use to a spectrum of submersible users are being designed for *Pisces* IV. Finally, IOS is involved in two proposals to measure forces produced by sea ice.

Formal consultation to other IOS groups has been provided to Tidal and Current Surveys for their Meteorburst tidal telemetry system, to Field Hydrography Section for a range-bearing study, and to Ocean Chemistry Division for a photoacoustic detector project.

## Electronics Technology Support

Calibration, repair and installation to support ships, hydrographic and oceanographic programs were satisfactorily performed during the year. The major equipment areas were radios, depth sounders, and positioning systems.

In the radio area, approximately 55 VHF/FM and 15 HF/SSB transceivers were maintained. Three obsolete HF/SSB transceivers were replaced with synthesized

multi-channel equipment. A BH-30 transceiver was increased in channel capacity and a CH150/BH-30 was interfaced to a new model 1 KW antenna coupler. A radio base station was installed at Tuktoyaktuk for radio communications with the charter vessel *Polar Circle* and radio station XMH59 at IOS and in contrast to last year, good communications were experienced. Efforts were expended in obtaining Department of Communications approval for an IOS RITY installation, and a watching brief was maintained over a HF data message terminal for possible IOS use.

The depth sounder group maintained 28 depth sounders plus numerous small sounders from four different manufacturers. Ten depth digitizers were serviced and a contract was awarded to upgrade them to H-series performance. A development contract was completed which saw three 50 KHz digitizers delivered to IOS and two 30 KHz digitizers to CHS Central Region. A short contract resulted in ten digital speed-of-sound circuits retrofitted into existing Skipper sounders. A sounder calibrator resulted in a Suggestion Award and a PILP award to industry.

Approximately 21 microwave positioning units, 15 Argo units, three satellite navigation systems, and Loran-C and Omega systems were serviced. Ships, launches and the barge *Pender* were fitted out for hydrographic purposes.

Support was provided to Computing Services in maintenance of the Kongsberg drafting system and new UNIVAC data circuits. *(Contact: W.R. Taylor.)*

## Industrial Liaison and Contracting

The Institute of Ocean Sciences has an established policy of conducting a significant portion of its program through contracts to the private sector.

In addition to contracting out directly, IOS participants in such government ventures as the Unsolicited Proposals (UP) program with the Department of Supply and Services (DSS), and both the Program for Industry/Laboratory Projects (PILP) and the Industrial Research Assistance Program (IRAP) with the National Research Council (NRC). IOS was involved to some extent in 116 contracts in the past year, ranging in value from less than one thousand dollars to approximately one million dollars, and with a total value in excess of $4.8 million. *(Contact: T.A. Curran.)*

# Oceanography

# Oceanography

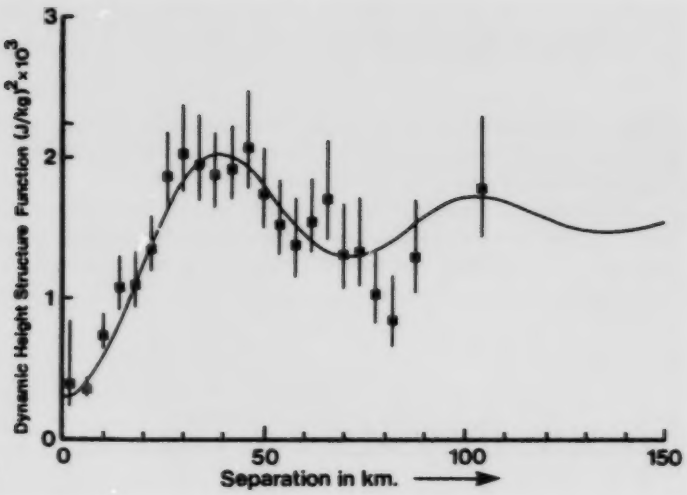
The oceanographic program at IOS includes ocean physics, ocean chemistry and ocean ecology. The oceanographic information on current systems and associated temperatures and salinities, on the chemistry of the ocean and associated pollutants, and on primary productivity and the lower trophic levels of the food chain, such as plankton, are provided to agencies engaged in environmental protection, to fisheries managers, to industrial concerns, defence, and to others who have a need for information about the oceans.

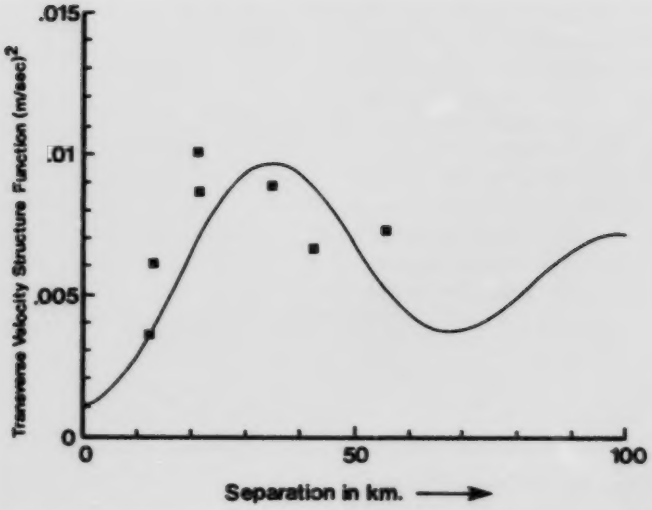
# Ocean Physics

The highlights of 1983 include some new developments and some activities which can be viewed as logical extensions of previous projects. Examples of the former would be the initiation of programs to examine oceanographic factors affecting sea ice motion in the Beaufort Sea, and the establishment of a program aimed at the development of methods of forecasting oceanic variables. Examples of extensions of ongoing work are the start of a field program to improve knowledge of the water properties and currents on the west coast of the Queen Charlotte Islands, and the first phase of an international experiment off Australia designed to test theories of continental shelf wave propagation. Other exciting developments came in the area of acoustic remote sensing of the ocean interior and optical remote sensing of near surface properties. However, any such short list is bound to be misleading as the great variety of activities described below will show.

## Coastal Zone Oceanography

Data acquired between 1979 and 1981 as part of the Coastal Ocean Dynamics Experiment (CODE) continued to produce results. An analysis of the statistical structure of oceanographic fields on the continental shelf demonstrates how dynamical constraints affect the structure of oceanographic fields. Given a prior knowledge of the structure of one field, e.g. the structure function of the dynamic height field, one can predict what the structure function of a related field, e.g. current velocities, should be. In this case the two fields are constrained by the dynamics of geostrophic balance. Operationally this information is of value in planning experiments. Historical data is usually in the form of conductivity and temperature versus depth. These can be used to estimate the dominant scales over which current fields will vary and so can be used to plan a current sampling scheme rationally. *(Contact: H.J. Freeland.)*

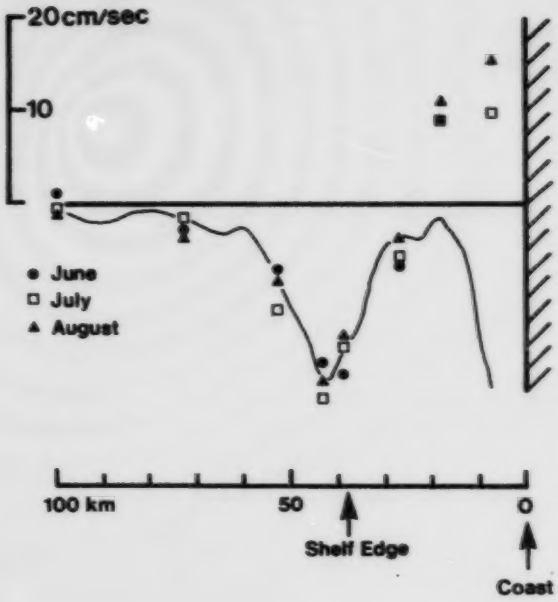



*The upper panel shows estimates of the structure function* $S(\rho)$ *of the dynamic height field* $D(x)$ *plotted against scalar displacement* $\rho = |\underline{\xi}|$ *. where* $S(\rho) = \overline{\{D(\underline{x}) - D(\underline{x}+\underline{\xi})\}^2}$*. The continuous line is a weighted least-squares fit of a simple functional form for the structure function* $S(\rho) = 2\sigma^2\{1 - (1 - \epsilon)\exp(-\rho^2/a^2)J_0(\rho/b)\}$ *, where* $\sigma^2$ *is the signal variance,* $\epsilon$ *is the noise level and a and b are two length scales. From that least-squares fit we can compute the expected transverse velocity structure function that is implied by geostrophy. This is plotted on the lower panel together with estimates of the structure function derived directly from the current meter observations. This plot indicates that the entire CODE data set is essentially in geostrophic balance, furthermore, the least-squares fit requires that* $a>>b$ *which indicates that the current field may be dominated by a few plane waves moving through the CODE area in geostrophic balance.*

Current meter observations acquired as the result of several discrete experiments off the B.C. coast since 1979, involving Coastal Zone Oceanography, Offshore Oceanography and Tidal and Current Surveys, were merged into one large synthetical description of the general current regime off the west coast of Vancouver Island and Queen Charlotte Sound. The general current field appears to be heavily dominated by the presence of a large annual cycle in the upper part of the water column with the result that monthly averages of currents computed from different years' data, but for the same month, show considerable consistency. The presence of a southward jet just seaward of the shelf edge during the summer months is

consistent with a response of the coastal waters to upwelling by favourable winds. *(Contact: H.J. Freeland.)*

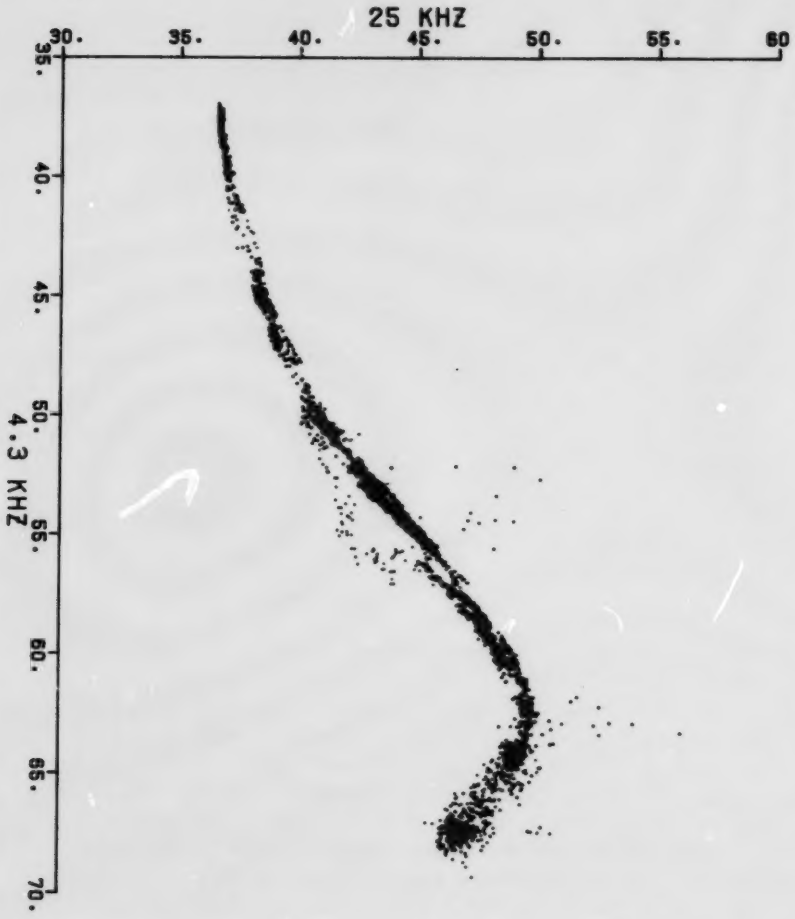



*The alongshore component of flow is plotted against distance from shore off Estevan Point, half way up the west coast of Vancouver Island, for three summer months. The data clearly show the presence of a southward flowing jet seaward of the shelf edge, and a nearshore northward flowing jet, the Vancouver Island Coastal Current. The former jet is observed to be only a summer feature, whereas the latter is present year round. A simple vorticity balance theory for the response of the water on a continental shelf and slope to upwelling favourable winds predicts a current profile as shown in the figure by the continuous line. In particular the theory predicts that the current shape is proportional to* $\frac{1}{H}\frac{dH}{dx}$ *where H(x) is the depth at a distance x offshore. The maximum of this function always occurs a short distance seaward of the shelf edge for any reasonable shelf/slope profile. The theory fails to account for the current field close inshore, which is not surprising, the nearshore current is driven by coastal buoyancy sources and probably only modulated slightly by the wind systems.*

IOS is participating in the Australian Coastal Experiment (ACE) in an effort to determine whether the oceanography of the continental shelf is controlled by the physics of shelf waves. The experiment is an international venture with major contributions from Canada (IOS), USA (Oregon State University and Florida State University) and Australia (CSIRO and the Royal Australian Air Force). In September, IOS personnel deployed six current meter moorings on the New South Wales Shelf and similar deployments were made by Oregon State and CSIRO. Tide gauges, deep pressure gauges, meteorological buoys and surface, satellite-tracked, drifting buoys were also deployed. The deployment period is six months and during that time CSIRO is conducting monthly CTD surveys and the RAAF is executing frequent AXBT surveys. *(Contact: H.J. Freeland.)*

Analysis of data from Observatory Inlet revealed new information on the internal hydraulic adjustment of flow over the sill to changing tidal speeds. The flow evolves through a sequence of modal responses, including critical flow with respect to the second internal mode, followed by a transition regime, followed then by critical flow with respect to the first internal mode. The intermediate step between first and second modes exhibits a condition, theoretically predicted but not previously observed in natural flows, known as virtual control with respect to second mode. In this state, flow over the sill crest is super-critical with a smooth hydraulic transition occurring some distance upstream of the crest and a sudden and turbulent reversion to sub-

critical flow some distance downstream. The flow was also studied with a small laboratory model. *(Contact: D.M. Farmer.)*




*Scatter plot of acoustic noise levels measured on the sea floor in Queen Charlotte Sound at two frequencies (4.3 and 25.0 KHz). Most of the noise is generated by the action of wind on the sea surface. At higher wind speeds bubbles entrained by breaking waves scatter and absorb the sound, providing some acoustical insulation and causing the upper right hand portion of the plotted points to curve over, as the higher frequencies are suppressed. Points lying above the principal curve show the influence of noise due to precipitation; points lying below show the effects of passing ships.*

Ambient noise in the ocean at higher frequencies (>4KHz) is being studied for its potential in the remote sensing of processes at the air-sea interface. Measurements during the summer in Queen Charlotte Sound confirmed that wind/noise relationships found in the deep ocean also apply on the continental shelf and demonstrated the possibility of separating from the signal contributions due to precipitation. However, further data collected during the winter revealed an unexpected change in spectral properties of the noise level at higher wind speeds. For winds greater than 12 $ms^{-1}$, noise at the higher acoustic frequencies appears to be attenuated and can actually decrease with increasing wind speed. The effect is attributed to scattering and absorption by bubbles near the ocean surface. The results can be inverted to provide both bubble population densities and size distributions. These are consistent with the few previously available estimates, but greatly extend the wind speed range for which such estimates are known. *(Contact: D.M. Farmer.)*

A range-gated Doppler sonar was used to resolve flow structure over sills. Measurements have also been made in undisturbed water, as part of a program to determine instrument sensitivity and other operational characteristics. The Doppler receiver was also incorporated in a prototype profiling device with which to test a novel approach for measuring sound speed through the refraction of narrow beams generated by a multi-element linear array. This work is being carried out with graduate students from the University of Victoria and the profiling study is being supported by NOAA. *(Contact: D.M. Farmer.)*

Forward scatter of sound over short path lengths is being explored for its potential for remote sensing of flow speed and microstructure across tidal channels. An experiment was carried out in Sansum Narrows using a single projector and three receiver elements. Simultaneous velocity measurements as well as temperature microstructure measurements were obtained for comparison with the acoustic data. This project is designed to test the viability of wave propagation theory in inhomogeneous media for inverting both phase and amplitude scintillations to recover horizontal profiles of flow speed and other properties of the flow in coastal waters. This work is being done jointly with the Wave Propagation Laboratory in Boulder. *(Contact: D.M. Farmer.)*

A prototype microscale profiler, FLY, was built and tested in conjunction with Tidal and Current Surveys. The profiler carries instruments to measure pressure, temperature and dissipation-scale velocity shear and is adaptable for very near-bottom profiling. *(Contact: W.R. Crawford, A.E. Gargett.)*

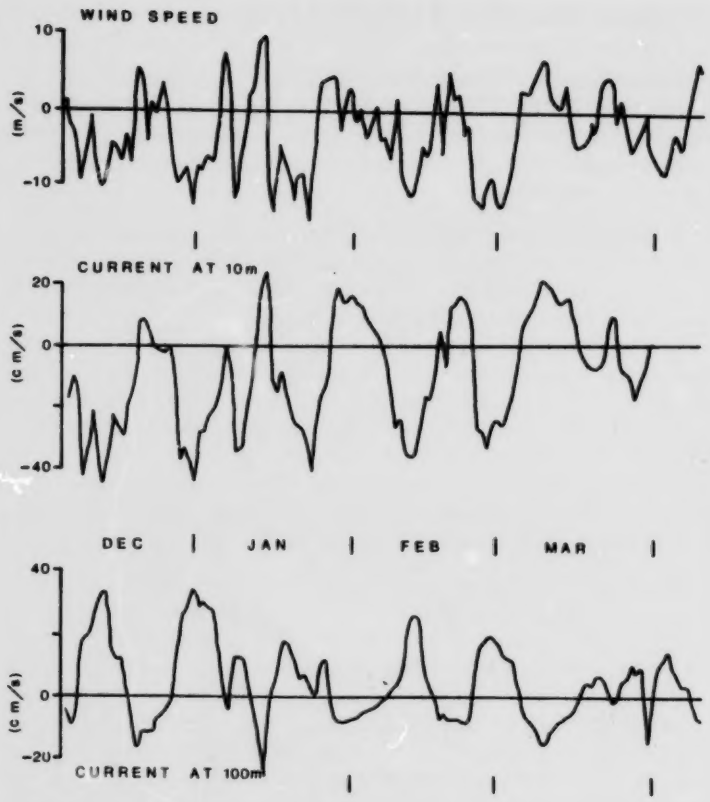
A critical evaluation was made of various methods used to derive the vertical eddy diffusivity $K_V$ assumed to characterize turbulent transport of mass across isopycnals in a stratified fluid. The most reliable estimates suggest that, for systems mixed by internal waves, $K_V = a_O N^{-1}$ is an improvement on the standard assumption of constant $K_V$. The parameter ao is a function of particular systems; for the ocean, a value of a $a_O \sim 1 \times 10^{-3} cm^2 s^{-2}$ can be derived. *(Contact: A.E. Gargett.)*

Analysis of Alice Arm and Observatory Inlet data showed that the deep water exchange in Alice Arm was more intense in the winter of 1981-1982 than in the

winter of 1982-1983. Deep water exchange in Alice Arm occurred between late December 1981 and early April 1982 when there was a seasonal increase in the density of the near surface waters because of reduced run-off and winter cooling. During this period, individual renewal events were observed and it appears that the timing and strength of these is controlled by the density fluctuation in Observatory Inlet. In Observatory Inlet energetic low frequency currents were observed at 10 m and 100 m that were 180° out of phase. These low frequency currents (~20 day period) are coherent with the local wind, with 50-70% of their variance accounted for by the wind. Coherent with the low frequency currents are the density fluctuations that appear to control the timing of the deep water renewal events in Alice Arm. *(Contact: D.J. Stucchi.)*

*The microscale profiler FLY was used during two cruises to Queen Charlotte sound during 1983. The large ring protected probes from the bottom during studies of tidal mixing over shallow banks.*

Tidal height, CTD and current velocity data are being used to examine the tidally-driven circulation in Observatory Inlet and Alice Arm. Analysis of the tidal height data has shown that there are large seasonal variations in the power withdrawn from the barotropic tide. A simple theoretical model and the current velocity data show that much of this power is being fed into a progressive, internal tide. This internal tide is generated by the interaction of the barotropic tide with the sill of Observatory Inlet. The power in the internal tide varies seasonally because of seasonal variations in the stratification of the water column. The barotropic tide also drives highly non-linear, internal motions in the vicinity of the sill. These motions are more rigorous during spring tides than neap tides and so more energy is available for mixing during spring. Because of this, a significant baroclinic current occurs at the beat frequency of the $M_2$ and $S_2$ tides. *(Contact: M.W. Stacey.)*




*Low passed, along channel winds and currents in Observatory Inlet (positive values are up inlet) during the winter of 1981/82. The resemblance between wind and currents is apparent.*

## Frozen Sea Research Group

During 1983, the scientific effort of the Frozen Sea Research Group was directed towards describing and understanding those physical processes which accomplish the transport and diffusion of water properties within the upper 1000 m of the ocean in the Arctic and across the ocean-ice and ocean-atmosphere interfaces. The major geographic focus areas were the channels between the islands in the Canadian Arctic archipelago and portions of the continental shelf which border on the Arctic Ocean and the Beaufort Sea. Some work was also carried out in the deeper waters of the Arctic Ocean overlying the Alpha Ridge. In support of these projects considerable effort was directed towards the testing and development of equipment and instrumentation. The investigational works were closely interrelated and new

insights gained in one area frequently had a profound influence on progress in another.

Substantial additional financial and personnel support was made available by the Office of Energy Research and Development (OERD) and by Transport Research and Development to enhance the level of oceanographic knowledge and understanding prior to hydrocarbon development and transportation within the Beaufort Sea and Northwest Passage.

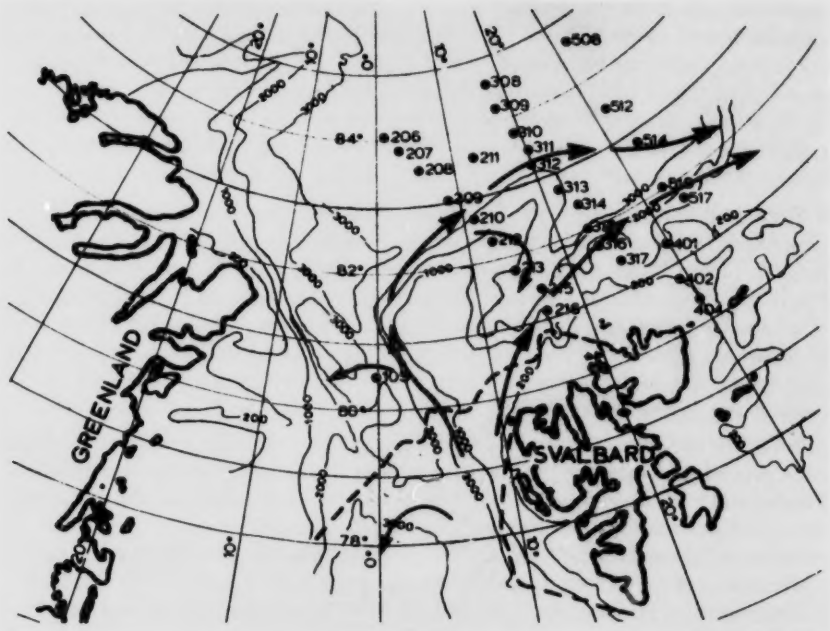
Interpretation of the early winter hydrographic data from the Beaufort Sea in 1979 was completed with the publication of a journal article and a technical report. Principal findings were a haline circulation on the Mackenzie Shelf and Slope driven by wintertime freezing, a systematic modification of Atlantic water temperatures near the continental margin and an improved knowledge of ocean circulation in this area. Interpretation of the more detailed observations of the haline circulation made in the spring of 1981 is continuing. A strong haline front was identified on the outer shelf, and a strong undercurrent over the outer shelf and upper slope of both the Alaskan and Mackenzie shelves was delineated. There is evidence that this undercurrent penetrates a significant distance into the archipelago. Data have been shared with the United States Coast Guard and with the Atmospheric Environment Service who are co-participants in the project. *(Contact: H. Melling.)*

A second year of field data were collected providing water level, water structure and current velocity information in and adjacent to the NW Passage. Analysis to date has provided information on surface current patterns in Prince of Wales Strait and Viscount Melville Sound and an understanding of the upward flux of heat from the Atlantic water in the region which warms the subsurface waters of the Northwest Passage which, when brought to the surface over sills in the central archipelago, contributed to the formation of polynyas or of thin unstable sea-ice covers. Water level data collected over 15 months in Prince of Wales Strait will permit determination of integrated channel flow from cross-channel pressure differences. *(Contact: R. Lake, H. Melling.)*

A program of water height measurement along the Canadian Arctic continental shelf was continued in cooperation with the Tidal and Current Surveys of the Canadian Hydrographic Service. Water pressure gauges were replaced at Mould Bay, Isaacsen, Audhild Bay and Pond Inlet to supplement existing permanent gauge sites and so to provide a record of pressure changes from the Beaufort Sea to the north coast of Ellesmere Island and across the archipelago. It is hoped that pressure information from other points in the Arctic Ocean will be acquired and the propagation of non-tidal water height anomalies will be investigated. These studies will be supplemented during 1984 by programs involving the deployment of current meter and CT chain moorings. The overall goal is to acquire a better understanding of water movement and water mass changes within the archipelago throughout the year. *(Contact: E.L. Lewis.)*

The analysis of data acquired north and east of Spitsbergen in the spring of 1981 is now complete. In this area the comparatively warm waters of the Western Spitsbergen Current enter the Arctic Ocean and details of this entry and subsequent

mixing are of great importance to studies of Arctic oceanography. It was found that the warm water flowed in two filaments, one next to the north coast of Spitsbergen and the other about 300 km to the north following the edge of the continental slope. Heat was lost from the West Spitsbergen Current above these filaments through the ice into the atmosphere, and generally by interweaving with colder waters to the north.




*The largest island in the Svalbard group is named West Spitsbergen and the heavy arrowed lines show the bifilamentary trajectory of the warm West Spitsbergen current as it enters the Arctic Ocean from the Atlantic. This current is the major oceanic heat source to the Arctic Ocean and Fram Strait, the channel between Greenland and Svalbard, shown above, is the only deep water connection between the Arctic Ocean and adjacent seas. The depth contours are shown. On the western side of the Strait, next to Greenland, the cold East Greenland current carries Arctic Pack Ice southward down the coast. This ice stream extends to the southern tip of Greenland, Cape Farewell, and then continues to follow the coast as it turns northwards to form the eastern boundary of the Labrador Sea. The sites of our oceanographic stations are shown as numbered dots on the figure.*

One outcome of these studies was the observation that near-surface waters in a broken and ridged ice field were normally slightly supercooled. This results from the non-uniform ice thickness and the variation of freezing point with pressure. The phenomenon has been noted previously in conjunction with floating ice shelves, particularly those in Antarctica where, 500 m below sea level, the freezing temperature is about 0.4°C below that of the same water at the surface. Any process

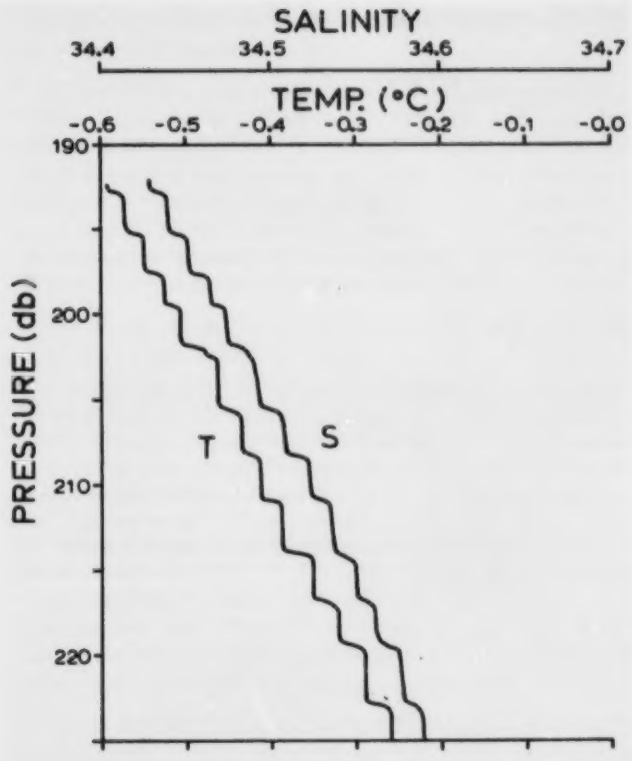
then causing vertical movement of such water enables it to become supercooled as the pressure is relieved and forms a potential heat sink for freezing. The same process occurs between the leads and ice keels of the Arctic Ocean but on a much smaller scale; it is discussed in Lewis and Perkin (1983). *(Contact: E.L. Lewis, R. Perkin.)*

Preliminary analysis of data acquired in the McMurdo Sound area of Antarctica in the fall of 1982 is now complete but more is planned for 1984. It is the most extensive survey of its type to date. In the spring of 1983 advantage was taken of the establishment of the CESAR camp over the Alpha Ridge in the Arctic Ocean and CTD surveys were run northward from the coast of Ellesmere and Axel Heiberg Islands out to the CESAR camp with an additional section joining them at the CESAR latitude running from the Makarov Basin to the Canada Basin. Of note is the extensive double diffusion indicated by a step structure in the Arctic thermocline which gradually becomes more diffuse near the coast. *(Contact: R. Perkin, E.L. Lewis.)*

Routine hydrographic profiling by CTD has provided numerous examples of thermohaline layering reminiscent of double-diffusive convection in the Beaufort Sea and Arctic Ocean. Weak gradients in these structures permit direct computation of the diffusive fluxes of heat and salt. These are found to scale well with laboratory data on similar structures. In the Beaufort Sea, the results indicate that very low heat fluxes are achieved by these processes (of the order of 0.02 $W/m^2$!), but that higher fluxes of a double-diffusive nature are encountered closer to the area of Atlantic-water inflow to the Arctic Ocean. *(Contact: H. Melling, D.R. Topham.)*

The OERD Ice/Ocean Dynamics Program began in 1983. The goal of this program is an improved understanding of the dynamics of the momentum transfer between the ocean and pack ice in ice-covered waters, and of those aspects of the dynamical oceanography of the Beaufort Sea pertinent to the short-term prediction of the sea-ice motion in this area. Attainment of this goal will provide a sound physical basis for the refinement of ice-motion prediction models used operationally in the Beaufort Sea. The region of prime interest is south of 73.5°N between 124°W and 141°W. The design of this program is still incomplete but an important aspect of the interaction is the direct transfer of momentum at the ice-water interface, usually parameterized as a drag coefficient. Since a major unknown is the drag contribution from downward projecting ice keels, this aspect has been selected for detailed study. Of particular interest is the interaction between keel-generated lee waves and flow separation, as it is the latter which is thought to make a major contribution to the overall keel drag. Numerical experiments are being designed to make use of data assimilation techniques to investigate the sensitivity of model predictions to input parameters and optimal data collection schemes for predictive use. *(Contact: D.R. Topham.)*

Preliminary qualitative results were obtained from a laboratory simulation of the circulation patterns generated by a salt flux imposed on the surface of a tank with a sloping bottom when the convective mixing penetrates the full depth of the tank. This study is relevant to circulation produced by sea-ice growth over the extensive shelves of the Arctic Ocean. Shadowgraph and dye studies reveal a thin density current along the sloping bottom, and that the return flows generate significant velocity shears throughout the depth of the "mixed" layer. *(Contact: D.R. Topham.)*

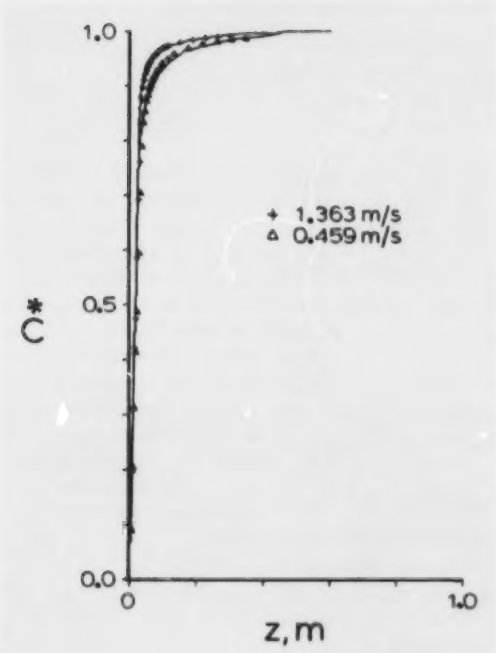



*Stepped profiles of temperature and salinity at the bottom of the Arctic Ocean thermocline. The steps are evidence of double diffusive processes effecting the transport of heat and salt. Each step is composed of a comparatively well mixed layer of water separated by a sharp gradient from its neighbour, a form of profile resulting from the 100:1 difference between the diffusion coefficients for heat and salt respectively at a molecular scale. Double-diffusion in the ocean is often obscured by other, more energetic, turbulent mixing processes but in the central Arctic Ocean, which is naturally quiet and is isolated from the wind by the ice cover, the steps can develop fully. These data were taken near the CESAR camp at 83° 33'N 88° 50'W during April 1983.*

A computer-based study of thermal diffusion in sea-ice covers was undertaken to investigate the observational requirements for the determination of vertical heat fluxes in sea-ice from ice temperature measurements. It was concluded that while existing measurement technology is probably adequate for the task, the necessary array complexity rules out the technique as a contender for simple vertical heat-flux measurement. *(Contact: H. Melling.)*

A general analysis of the conductivity cell response of CTD instruments was carried out in which the necessary conditions for the existence of a linear transfer function are established and are shown to be satisfied in the case of salinity changes but not that of temperature changes. Detailed response characteristics were calculated for both the Guildline and Neil Brown instruments. The calculations cover a range of instrument fall speeds. A paper on the transient behavior of conductivity sensors has been prepared for publication. A contract has been let to the Applied Physics Laboratory of the University of Washington to determine the response of the Guildline Mk IV temperature and conductivity sensors. In the case of the C-cell it is hoped to determine separately the response to salinity and to temperature and to

confirm the non-linear behavior expected to arise from diffusion effects. *(Contact: D. Topham, R. Perkin.)*




*Response of conductivity cells used as sensors on oceanographic instruments. Shown is a comparison between the computed step response of the 3 cm cell used on a Neil Brown conductivity-temperature-depth fish and the measured response given by Gregg et al. (1982) at 0.459 m/s and 1.363 m/s lowering rates. The symbols denote computed response and the lines measured response. C star is the normalized conductivity and Z is the distance travelled by the probe.*

Systematic errors in the Guildline CTD due to leakage, temperature cycling, etc. and the electronic performance of both analog and digital system components were investigated, resulting in improvement in the understanding and quality of data obtained from the instrument. Results of this work have been discussed with Guildline Instruments. An advanced designed of the salinity (i.e. C/T) chain involving distributed sensor electronics and digital data transmission is being supplied by Applied Microsystems Ltd. and tested in Saanich Inlet. The accuracy of sensors is specified to provide a salinity to ±0.02, assuming insignificant fouling. *(Contact: R. Sudar.)*

Because of the absence of a commercially available water sampling bottle suitable for use on aircraft-based hydrographic surveys, a bottle of small cross-sectional area (to facilitate sampling through holes in sea ice), low thermal diffusivity (to minimize sample freezing problems) and low immersed weight (to minimize cable weight requirements) is being designed. The first requirement necessitated in-line sealing caps, which in turn required careful design for correct hydrodynamic performance and flushing. This part of the design is now complete. Evaluations of potential materials for the bottle and its seals are currently being undertaken, and a decision

regarding fabrication technique (moulding or machining) has yet to be made. *(Contact: H. Melling, D.R. Topham.)*

A rigid current meter mooring was developed for Arctic areas where the horizontal component of the earth's magnetic field is inadequate to give a directional reference. It was deployed in Austin Channel during the spring of 1983. Several tests of rigidity and a trial mooring with both conventional and 'Arctic' current meters was deployed in Satellite Channel on the west coast. At speeds of one knot direction held to ±5 degrees or better over a 38 metre length. The orientation of the mooring on the seafloor is determined by uncaging a gyro after the mooring is in place. The gyro is then returned to the surface and read. *(Contact: S. Moorhouse.)*

The results of careful laboratory measurements on the drift characteristics and stability of Paroscientific pressure transducers which are commonly used in sea-floor tide gauges are being investigated. Preliminary results suggest that for the 30 db-range sensors, calibraton drift over 1 year does not exceed 1 mb, and that the drift is predictable and thus correctable to within a few tenths of a millibar. This order of accuracy is adequate for the estimation of flows in channels from cross-channel pressure differences. *(Contact: H. Melling, W.R. Buckingham.)*

During the past several years considerable attention has been paid to the Fram Strait Project, proposed by the Comité Arctic International as a major international cooperative study in polar oceanography. Regretfully and after considerable efforts to raise the necessary funds, this initiative has been abandoned and the Management Group disbanded, a victim of changed economic circumstances, particularly in the petrochemical industries. *(Contact: E.L. Lewis.)*

Group members have also been intimately concerned with the work of international advisory organizations (e.g. SCOR Working Groups) and national committees. They have also been called upon to provide technical comment on the EIS for Beaufort Sea Development, and at public hearings.

The Group was invited to provide technical and scientific input into the Beaufort Environmental Monitoring Project (BEMP), a project initiated by the Department of Indian Affairs and Northern Development (DIAND) which strives to produce recommendations for a sound and defensible monitoring program which could potentially accompany industrial development in the Beaufort area. *(Contact: H. Melling.)*

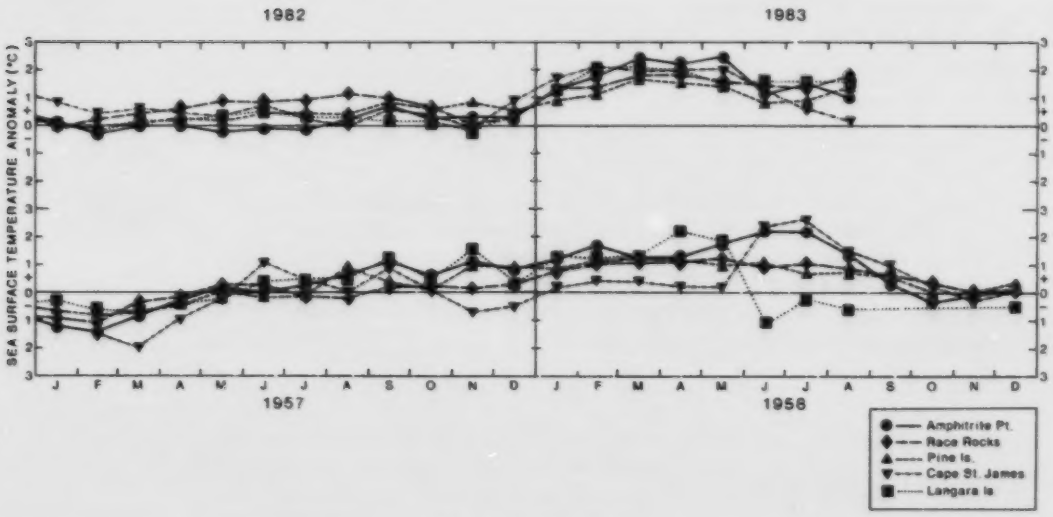
## Offshore Oceanography

Current and water property measurements collected during the Coastal Oceanic Dynamics Experiment (CODE) revealed the formation of a mesoscale baroclinic eddy off the central coast of Vancouver Island in the fall of 1980. The eddy core was characterized by near-surface currents of 50 $cms^{-1}$, a radius of 50 km and mid-depth

isopycnal displacements of 50 m. Growth of the eddy is sustained through dynamic instability of the prevailing coastal current consisting of a southeastward wind-driven surface current and northwestward flowing California undercurrent. A study of the energetics shows that roughly 82% of the energy flux from the mean to the eddy field is via baroclinic instability and that the characteristic time scale for the eddy growth is 25±10 days. *(Contact: R.E. Thomson.)*

In conjunction with the Australian Institute of Marine Sciences (Townsville), six months of current and temperature data were collected from Raine Island Entrance (11°38′ south latitude) on the Great Barrier Reef. These data show that tidal motions lead a pronounced upwelling of cold, nutrient-rich continental shelf water on to the reef and that the seaward eddy heat flux of 0.79±1.01 cal $cm^{-2}s^{-1}$ at the outer reef corresponds to onshore fluxes of nitrate, phosphate and silicate of $0.9(\pm1.2)\times10^{-2}$ mmol $m^{-2}s^{-1}$, $0.7(\pm0.9)\times10^{-3}$ mmol $m^{-2}s^{-1}$ and $0.6(\pm0.8)\times10^{-2}$ mmol $m^{-2}s^{-1}$ respectively. Details of the upwelling mechanism were also described. *(Contact: R.E. Thomson.)*

A detailed study was completed of barotropic and baroclinic continental shelf waves of diurnal period off the west coast of Vancouver Island. Results suggest that the larger amplitude shelf waves consist primarily of first mode baroclinic oscillations that are significantly modulated by seasonal variations in the prevailing alongshore current over the continental shelf and slope. *(Contact: R.E. Thomson.)*

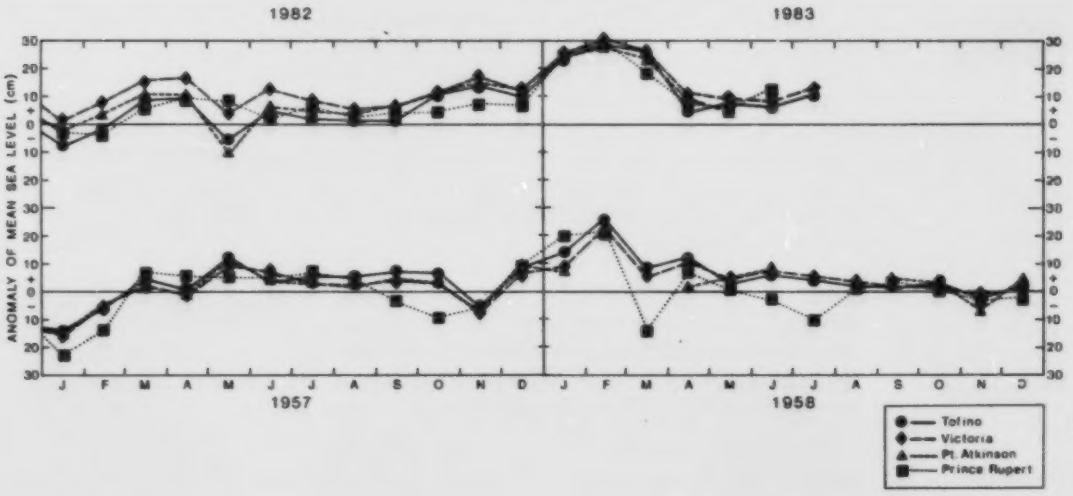

1982
1983
SEA SURFACE TEMPERATURE ANOMALY (°C)
J F M A M J J A S O N D J F M A M J J A S O N D
1957
1958
Amphitrite Pt.
Race Rocks
Pine Is.
Cape St. James
Langara Is.

*Anomaly of monthly mean sea-surface temperature (°C) from exposed coastal stations: Race Rocks, Amphitrite Point, Pine Island, Cape St. James and Langara Island (south to north)—1982-1983 and 1957-1958. Anomalous warming of coastal waters occurred all along the Pacific coast of North and South America during the 1982-1983 ENSO. The largest warming occurred along the coast of northern Peru in spring-summer 1983. The anomaly here was as large as +7°C, the largest ever recorded!*

Winds measured over the continental shelf off Vancouver Island during the summers of 1979 and 1980 were compared with winds computed by the National Marine Fisheries Service (Monterey). It is shown that the computed winds fail to resolve transient wind patterns and that such winds are only representative of oceanic winds for time variations of longer than two days. Spectra of the observed winds suggest a $k^{-5/3}$ law behavior (k is the horizontal wave number) consistent with the existence of a mesoscale, two-dimensional, cascading enstrophy inertial range. *(Contact: R.E. Thomson.)*

The Northeast Oceanic Dynamics Experiment (NCODE) was begun in May to study the circulation and long wave propagation along the 300 km west coast of the Queen Charlotte Islands. Characterized by a narrow (5 km) continental shelf, steep slope and strong winds, this region is one of the last oceanographic frontiers of the British Columbia coast. Preliminary results for the current and satellite-tracked drogue studies reveal a complex flow pattern in this area with a coastally-trapped, clockwise eddy off Cape St. James at the southern end of the Queen Charlotte Islands and mesoscale meanders and eddies off the central portion of the Islands. There is both theoretical and observational evidence for strong bottom-trapped current oscillations over the outer slope. *(Contact: R.E. Thomson.)*

During 1983 two cruises along Line P and three other lines between the Canadian west coast and Station P were made; one in March and the other in August.




*Anomaly of monthly mean sea level heights (cm) from representative coastal tidal stations: Victoria, Tofino, Point Atkinson (near Vancouver) and Prince Rupert (south to north) 1982-1983 and 1957-1958. Anomalous rise of mean sea level apparently occurred all along the Pacific coast of North America. (We have no data to indicate such a rise occurred along the South American coast.) It appears that the rise occurred about a month earlier at southern California shores.*

The 1982-83 El Nino-Southern Oscillation (ENSO) event is now considered to be the largest global anomaly of the ocean-atmosphere system of this century. The earliest suggestion of this anomaly was the drop in atmospheric pressure in the southeast Pacific Ocean and a rise of pressure over Australia during the summer of 1982. This was followed by the weakening of the trade winds over the equatorial and tropical Pacific. By the latter part of 1982 it became evident that a major climatic anomaly was occurring. In the eastern equatorial Pacific sea-surface temperature anomalies were as large as +5°C. Along the Pacific coast of North America an anomaly of +2°C occurred off Mexico and by the early part of 1983 the development of this anomaly extended as far north as off the Pacific coast of Canada. The ENSO effect along the Canadian coast was featured by increasing sea-surface temperatures especially during December 1982 - March 1983. A corresponding rise of mean sea level occurred during the same period. A maximum anomaly of sea-surface temperatures (+2.5°C) was reached during March-May 1983 while the highest anomaly of mean sea level (25-30 cm) was reached in February.

Oceanographic data taken along Line P during March 1983 revealed that the warm water intrusion associated with the 1982-1983 ENSO was restricted to less than 250 km off the coast. Comparison with the 1957-1958 ENSO effect indicated that while the behavior of ocean water along the coast was similar, both in terms of sea surface temperature and mean sea level, the areal extent of the earlier ENSO was many times greater than the 1982-83 event. However, the magnitude in 82-83 of the anomalies along the coast appears to be greater.

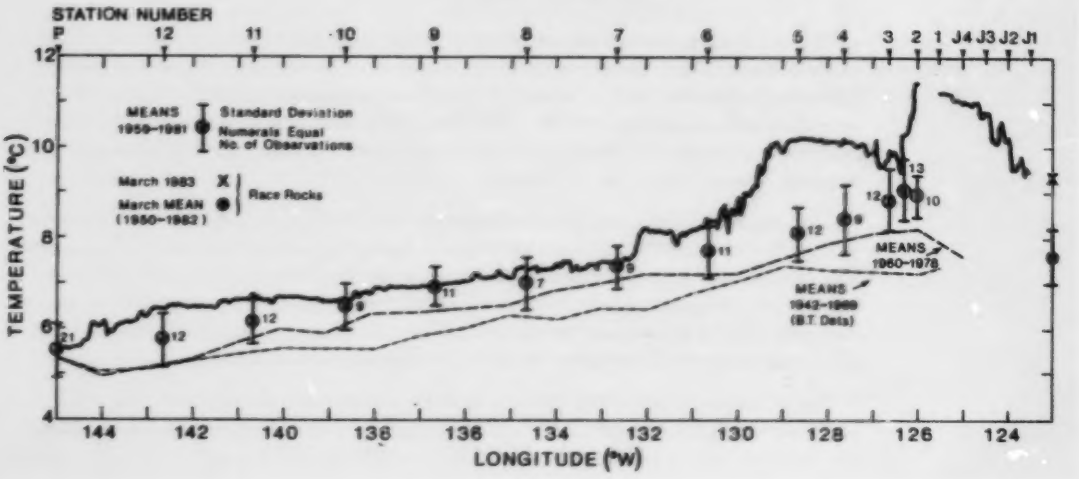
The development of the ocean climate anomaly during 1982-1983 affected the ecosystems of the coastal waters off both the North American and South American coasts. Along the California coast the rise in the anomaly of SST and mean sea level was accompanied by the appearance of *Pleuroncodes planipes* (pelagic red crab). Its previous occurrences were in 1941 and 1957-1958, which also were ENSO years. Similarly, barracuda appeared off California during 1983 as they did in 1958 and 1941. The occurrence of Pacific bonito, swordfish, green sea turtles and many sunfish off the B.C. coast is likely to be due to the ENSO effect, as it was during 1957-1958. *(Contact: S. Tabata.)*

Studies of two-dimensional turbulence included a theoretical investigation of the ability of turbulence to impress its characteristic scales upon phytoplankton concentrations, leading to patchiness and, the comparative roles of the enstrophy subrange and the large scale eddies in the relative dispersions of oceanic and atmospheric drifters. *(Contact: A.F. Bennett.)*

Inverse theory was used to estimate the efficiency of an array of seafloor-mounted pressure gauges and acoustic tomography probes for observing tides and individual interannual variations. *(Contact: A.F. Bennett.)*

An on-going upper ocean dynamics study was continued with the analysis of historical data. A ship-of-opportunity program was started in May using two ships on trans-Pacific routes. Surface temperature and salinity were recorded at one minute intervals, representing an order of 200 m spatial resolution. Recordings

showed many locations where salinity gradient was in the order of 2‰ per km and where temperature gradient was in the order of 5°C per km. On two of the trans-Pacific crossings, XCTDs were deployed. Through analysis of the time-series of such sections, it appears that the dynamics of the warm water off Vancouver Island in the summer months may be closely connected with the fresh water run-off from the Columbia River. Analysis underway will improve the description of the situation. *(Contact: M. Miyake.)*




*Sea-surface temperatures along Line P (between the southern coast of B.C. and Station P). The largest anomaly of SST occurred in a band 250 km off the coast, east of Station 12.*

## Forecast Methods

In the course of joint three-dimensional numerical model (4 km mesh) studies with the University of Hamburg, an improved barotropic tidal calibration and simulation of tidally-induced residual currents was achieved. Attention is now being directed to improving the density-driven circulation in the model. *(Contact: P.B. Crean.)*

Work is continuing on the development of a buoyant spreading upper-layer model of the shallow plum formed by the tidally modulated discharge from the Fraser River spreading over denser water in Georgia Strait. Extensive field data were analyzed to show the tidal and seasonal changes in distributions of velocity, salinity and layer thickness throughout the plume. Sensitivity trials of the model have been completed

and comparison of the modelled and observed distributions are in progress. This work is being carried out under contract. *(Contact: P.B. Crean.)*

A higher resolution (2 km mesh) vertically-integrated, barotropic model of mixed tides in the overall region, including the areas between Vancouver Island and the mainland coasts of B.C. and Washington, was developed and is undergoing calibration. The model will provide data for input to an extended version of the buoyant spreading upper-layer model referred to above, as well as an improved simulation of the tidally-induced residual circulation. *(Contact: P.B. Crean.)*

The accuracy and economy of finite element methods in tidal and storm surge models was studied. Some methods were found to be competitive with explicit finite difference schemes. Further investigations have suggested accurate choices of boundary conditions, and element size and shape. External requests for the tidal analysis and prediction programs have brought the number of worldwide users to over 50. *(Contact: M.G. Foreman.)*

The concept of diffusive kinematic waves was invoked to account for the very slow travel of the 1960 Chilean earthquake tsunami on the west coast of Canada. The traditional Lagrange formula for the velocity of long gravity waves such as tsunamis is not applicable in frictionally-dominated coastal inlets and river systems. Tsunami forerunners have been explained qualitatively as lateral waves which are diffracted long waves at continental shelf edges. *(Contact: T.S. Murty.)*

The influence of ice cover on long gravity waves such as tides and storm surges was examined in Canadian waters. Study showed that a marginal ice cover damps the crests much more strongly than troughs. *(Contact: T.S. Murty.)*

At the request of various UN agencies, several papers dealing with water systems, storm surges, tides and movement of oil slicks in the Bay of Bengal, Gulf of Oman and the Arabian Gulf were prepared. *(Contact: T.S. Murty.)*

A regular grid linear finite difference model was used in conjunction with an inverse model to obtain the best possible fit to available observations of the $M_2$ tidal constituent to the Dixon-Hecate-Charlotte system. This work provided $M_2$ cotidal charts for Hecate Strait but confirmed the need for further field measurements in Dixon Entrance and the mouth of Queen Charlotte Sound. An irregular triangular grid was prepared to provide a basis for subsequent, more detailed models. *(Contact: R.F. Henry.)* A storm surge flood delineation study for Tuktoyaktuk, NWT and the town's immediate environs was undertaken on behalf of Environment Canada. The final product of this contract will be a map showing the area threatened by flooding in the event of a "100-year" storm surge. *(Contact: R.F. Henry.)*

Advice was supplied to the World Meteorological Organization on field programs required to improve the performance of storm surge prediction systems in countries bordering the Bay of Bengal. *(Contact: T.S. Murty, R.F. Henry.)*

## Remote Sensing

Work continued on the fluorescence line image sensor being built for IOS to map sea surface phytoplankton concentrations. Various instrumental effects caused by the CCD imaging elements were located and largely corrected. Flight tests were conducted in December.

The image processor system was transferred from the shared 11/34 computer to a dedicated machine. The original OVAAC-8 software was supplemented by programs to display and rectify viable and thermal imagery from the NOAA weather satellites and water colour (phytoplankton pigment) imagery from the Coastal Zone Color Scanner on Nimbus 7. A collection of imagery of the B.C. coast is being rectified and analyzed in support of physical and biological studies of Hecate Strait, Dixon Entrance and the west coast of Vancouver Island. Imagery of the east coast of Canada and of the Beaufort Sea is also being collected.

An airborne water-colour survey in the western Arctic, off the Mackenzie Delta, was carried out under contract in conjunction with two Dome Petroleum whale surveys. The IOS 256-channel spectrometer was flown on both operations, in August and September, each involving some 20 flight lines extending 90 km north from the coast. The project, funded through DSS, aims to compare whale distributions with silt and phytoplankton distributions deduced from the water colour observations.

Analysis of data collected in international programs continued, and plans were made for future cooperative ventures using the fluorescence line imager in 1985-86. *(Contact:. J.F.R. Gower.)*

## Computing Services

A Sperry DCP/20 front-end communication processor was installed during April 1983 to replace the 25-year-old CTMC communication controller. This interface to the Sperry 1100 mainframe will allow higher speed computer graphics and protocol flow control (XON/XOFF) to intelligent devices. Although not fully operational by year-end, operational status was anticipated by January 1984. In spite of the difficulties experienced with installation, it is expected to fulfil its design goal of providing a cost-effective growth capability for communications with the mainframe. Furthermore, it is supported by new software development by Sperry, whereas the old CTMC subsystem is not.

The Datacom network was also enhanced during 1983 by the replacement of 4 BC Tel 300 bps, dial-in modems with Microcom 300/1200 bps modems. These new modems have the additional ability to provide a fully error-corrected telephone link, provided the calling terminal also uses a Microcom device. For off-site users, this

means the communications quality via dial-up telephone lines can now be as good as on-site, direct communication.

The DATAPAC usage via the IOS Datacom network continued to expand during 1983. Whereas in the past most traffic was incoming, during 1983 more applications were initiated using outgoing calls on DATAPAC. For example, access to remote electronic mail systems and remote databases was established.

In March 1983, a small, Hewlett-Packard flat-bed plotter was acquired. Although used during the remainder of 1983 by the Ocean Information section, plans are to interface this plotter to the mainframe for access by all interested computer users during 1984.

Just before the end of the year, level 10R1A of the FORTRAN compiler, Sperry's ANSI '77 implementation, was installed. Considerable work was necessary to convert software libraries to this level, as certain, non-compatible changes were required to implement ANSI '77 features and conventions.

Eleven personal and desktop computers were introduced throughout the Institute. The trend is anticipated to continue as this technology matures. For certain types of applications, such small, dedicated processors are more cost-effective than larger, shared systems. *(Contact: R.E. Johns.)*

# Ocean Chemistry

The major objective of the Ocean Chemistry Division is to provide expertise, advice and a scientific perspective on both short-term and long-term problems associated with the chemical aspect of the ocean environment through both monitoring and research activities. Five areas are of prime concern: ocean pollution, ocean climate, ocean fluxes, ocean circulation and ocean productivity. The major effort is directed towards basic understanding of the long-term consequence of anthropogenic manipulation of the natural environment, but a balance is also struck by studying the short-term environmental impacts of societal intrusion.

## Alice Arm/Amax Studies

This program, to fulfil the requirement for baseline knowledge and understanding of chemical processes affecting the distribution of tailings into the fjord, was continued in 1983. There are three areas of interest: sea water chemistry, pore waters and sedimentary processes.

A cruise was conducted in July to study the dissolved and particulate mercury in the water column of Alice Arm, using a semi-automated, gold-bead technique. Analysis continued of lead isotopic ratios in soluble and total lead samples from an October 1982 cruise by clean laboratory/mass spectrometric method for tracing and assessing the tailings-derived lead in Alice Arm. *(Contact: C.S. Wong.)*

Time-series measurements of pore waters in Alice Arm continued. Metal availabilities from tailings and from natural sediments were also studied using an HCl-leaching approach. The study indicated, as an example, that zinc in tailings was only 10% of the total while in natural sediments was about 50%. *(Contact: J.A.J. Thompson.)*

Sediment trap material and tailings were analyzed for metals, organic carbon, chlorophyll-a, microscopy and X-ray diffraction assay, and data were compiled into a 3-part data report on chemical oceanography, covering particulates, sediment trapping and coring. *(Contact: R.W. Macdonald.)*

Metal-binding protein (MBP) and total metal contents in the tissues of King Crabs from the fjord were also analyzed at the request of Fisheries Management. *(Contact: J.A.J. Thompson.)*

## Coastal Pollution

The objective of this program is to understand organometallic species and the detoxification mechanism of metal-protein complexes (metallothioneins) in marine organisms and their transformation mechanisms in the marine environment so that environmental significance of "pollutants" can be assessed in a meaningful way.

Major effort was expended on the metal binding protein (MBP) study, particularly on methodology development. Further development of the polarographic assay technique, by using a cell temperature of 5-7°C and a modification of the Brdicka electrolyte, pushed the detection limits to less than 1 $\mu$g MBP $L^{-1}$. Improvements by removing interfering material by denaturation, using alcohol or heat, led to better estimates of MBP in two local clam species, *Protothaca staminea* and *Venerupis tenerima*. Denaturation removes half the signal contributors. This approach is also being applied to the assaying of MBP in oyster tissues from areas around Crofton, B.C. A comparison was made of this technique with the immunoassay method for MBP used in Batelle NW Laboratories at Sequim, Washington. *(Contact: J.A.J. Thompson, B.I. Imber, S.L. Ward.)*

A project was also initiated to study metal-binding proteins in organisms collected from the Juan de Fuca Ridge hydrothermal vents in cooperation with the University of Victoria. *(Contact: J.A.J. Thompson, V. Tunnicliffe.)*

Arsenic speciation and budget in Rupert Inlet and the Alice Arm area was studied

as a cooperative project with Royal Roads Military College with an enlarged sampling regime including plankton and riverine material. *(Contact: J.A.J. Thompson, K. Reimer.)*

## Hydrocarbons and Pesticides

The objective of the hydrocarbons and pesticides program is to advance the knowledge of the occurrence, pathways and fate of hydrocarbons (natural, petroleum-based, chlorinated and pesticidal) in the marine environment.

The emphasis of the 1983 program was methodology development for the assay of polycyclic aromatic hydrocarbons (PAHs) in mussel tissues and the assay of crude oil and radioactivity-labelled hydrocarbon to study the fate and pathways of Prudhoe Bay crude in the ocean enclosed experiment described under SEAFLUXES.

The suitability of freeze-dry and Soxhlet extraction methods for quantifying hydrocarbons in mussel tissues using gas chromatograph/mass spectrometer/computer system (GC/MS/DS) was established experimentally.

Three experimental techniques were developed and used in the SEAFLUXES crude oil/dispersant experiment. These were: n-(1-$^{14}$C) hexadecane labelling of crude oil, *in situ* fluorometry and epifluorescence microscopy. The *in situ* fluorometry indicated that the bulk of the oil mixed with dispersant, Corexit 9527, resulted in a form filterable by 1-$\mu$m filters and associated with detritus matter. The epifluorescence microscopic technique for enumeration of bacteria in the degradation experiment was found to be applicable to visual examination of oil droplets as small as 0.1 $\mu$m or less. *(Contact: W.J. Cretney, J. Li.)*

## Fjord and Arctic Chemistry

The objective of the program is to gain new knowledge of the environmental factors controlling the circulation and sedimentation in B.C. fjords and in the western Arctic. Such new knowledge will contribute to environmental impact statements and assessment of pollutant effects associated with industrial development.

Field activities were devoted to the Alice Arm fjord system as described under Amax. Lead-210 dating technique was applied to sediment cores from seismically well-characterized sites in the Kitimat fjord system and to cores taken in the Strait of Georgia to study anthropogenic vs. natural inputs of metals into the marine sediments. *(Contact: R.W. Macdonald.)*

Compilation of existing chemical data relating to the Beaufort Sea and N.W.

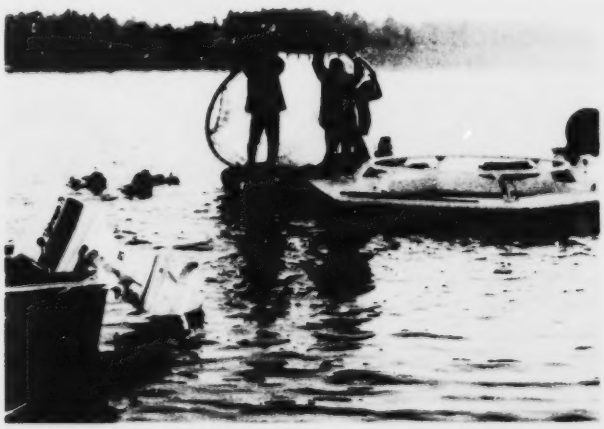
Passage, giving "best estimates" of budget and fluxes of hydrocarbons, metals and nutrients, was completed in conjunction with Ocean Information Division. Natural inputs were estimated to be comparable to the magnitude of projected wastes from oil exploration up to the year 2000. Ocean Chemistry Division also played an active advisory role in 1983, such as by preparing a document on environmentally-acceptable levels of metals in drilling products and by reviewing the Environmental Impact Statement for Beaufort Sea development. *(Contact: R.W. Macdonald, W.J. Cretney.)*

## Ocean Dumping

Quality control of the chemical analysis of metals in sediments is a priority in the management of the ocean dumping permit system. A laboratory performance check was designed. Advice was provided relating to the disposal of dredged material at B.C. Place in Vancouver, the disposal of Amax mine tailings, the monitoring of Arctic mine tailings and the U.S. Borax project in Boca de Quadra, Alaska. *(Contact: C.S. Wong, J.A.J. Thompson, R.W. Macdonald.)*

## Ocean Flux

Ocean flux experiments were carried out under two international cooperative programs: SEAFLUXES and PARFLUX.



*Launch day in Saanich Inlet for the SEAFLUXES program*

With funding assistance from the International Development Research Centre (IDRC), the SEAFLUXES program involved a cooperative study at Patricia Bay with participants from Shandong College of Oceanology, the 3rd Institute of the Chinese National Bureau of Oceanography, the Department of Oceanography at U.B.C. and IOS. The study investigated the pathways and fate of Prudhoe Bay crude oil premixed with a chemical dispersant, Corexit 9527, and the biological effects of the dispersed oil and the dispersant alone on the planktonic and bacterial communities. A radioactive tracer, n-($^{14}$C) hexadecane, was added in minute quantity to label the crude oil. The total oil concentration decreased to one-tenth of the initial addition in 10 days. About 70 percent of the $^{14}$C-n-hexadecane was degraded after 9 days. The epifluorescence work indicated that the bacteria elaborate some material that coats the oil. At levels close to 10 mg $L^{-1}$ of the crude oil, plankton growth was severely limited. *(Contact: C.S. Wong.)*

Consultations took place with representatives of IDRC, U.B.C. and the Chinese agencies involved to draft a three-year proposal for Canada/China cooperation relating to the Marine Ecosystem Enclosed Experiment. *(Contact: C.S. Wong.)*

Another international, cooperative program, PARFLUX, involving Woods Hole Oceanographic Institution and IOS, yielded exciting results. Two cruises, one in the spring and the other in the fall, were conducted to retrieve and relaunch the automated moored sediment traps at depths of 1000 m and 3800 m, as well as a large system at 3900 m for natural radiocarbon study. Three seasonal peaks of particulate flux into deep ocean were observed in the time-series; in May, August and October. A change of an order of magnitude was evident between the low and high flux season, implying that the existing "snapshot" approach by flux investigators could not obtain a quantitative picture revealed by the time-series approach. The flux rate was also found to be of the order of 200 m $day^{-1}$ for particles; about 2-3 times higher than what was accepted in the past. *(Contact: C.S. Wong.)*

## Marine Carbon Research Centre

The Centre, now in its fifth year, is focussing on the marine aspects of the global carbon dioxide ($CO_2$) cycle by conducting research, monitoring and modelling activities. The recent controversy over the U.S. Environmental Protection Agency's report on the greenhouse effect of $CO_2$ and the environmental consequences, coupled with a caution from the U.S. National Academy of Science, brought attention again to the lack of understanding of the crucial mechanisms of the ocean's capacity to absorb atmospheric $CO_2$. Signals of climate warming are vague at present, masked by background noise of natural cycles. However, they do indicate a possible increase of 0.1-0.5°C per decade, a much clearer signal by the year 2000 and a possible warming of $3 \pm 1.5$°C due to future $CO_2$ doubling with more dramatic heating of up to 2-3 times the global average rise in polar regions, including the Canadian Arctic.

*A sediment trap being deployed from* CSS Parizeau *in October 1983.*

Oceanic $CO_2$ monitoring is an essential tool in recognizing the first signals of oceanic $CO_2$ increase and in establishing the secular increase and long-term variability. The Centre took a lead rôle in conducting the first meeting of working group-75 on oceanic $CO_2$ monitoring of the Scientific Committee on Oceanic Research (SCOR). The meeting at IUGG in Hamburg, F.R. Germany was called to map out a global strategy, to define the precision of measurements required for $CO_2$ signals and to review various national capabilities for international cooperation. The oceanic $CO_2$ monitoring program at IOS continued to use three types of platforms: ships-of-opportunity, research cruises along Line P and the Cape St. James lighthouse. $CO_2$ time-series, oceanographic properties and productivity data for research and modelling purposes were provided by 2 ships-of-opportunity, the *Canada Ace*, between Tokyo and Richmond, B.C. and the *Lillooet* between Sydney, Australia; Noumea, New Caledonia and Richmond, B.C. The ships-of-opportunity program was assisted by funds from the Office of Energy R&D of the Department of Energy, Mines and Resources. This included development of a shipboard automated gas chromotograph system for atmospheric and oceanic $CO_2$ and the testing of the system on the *Lillooet* by IOS personnel. While on board IOS personnel also conducted work on continuous chlorophyll-a, conductivity-temperature sensing and nutrient sampling. *(Contact: C.S. Wong.)*

Research and modelling activities in 1983 were concentrated on working up atmospheric $CO_2$ data from Ocean Station P, Alert and Sable Island to establish the trend of atmospheric $CO_2$ increase, characteristics of the seasonal cycle and long-term natural variation. The data set has revealed a long-term atmospheric $CO_2$ growth rate of about 1.4 ppmv year $^{-1}$, with slight dips in the spline curves in 1976

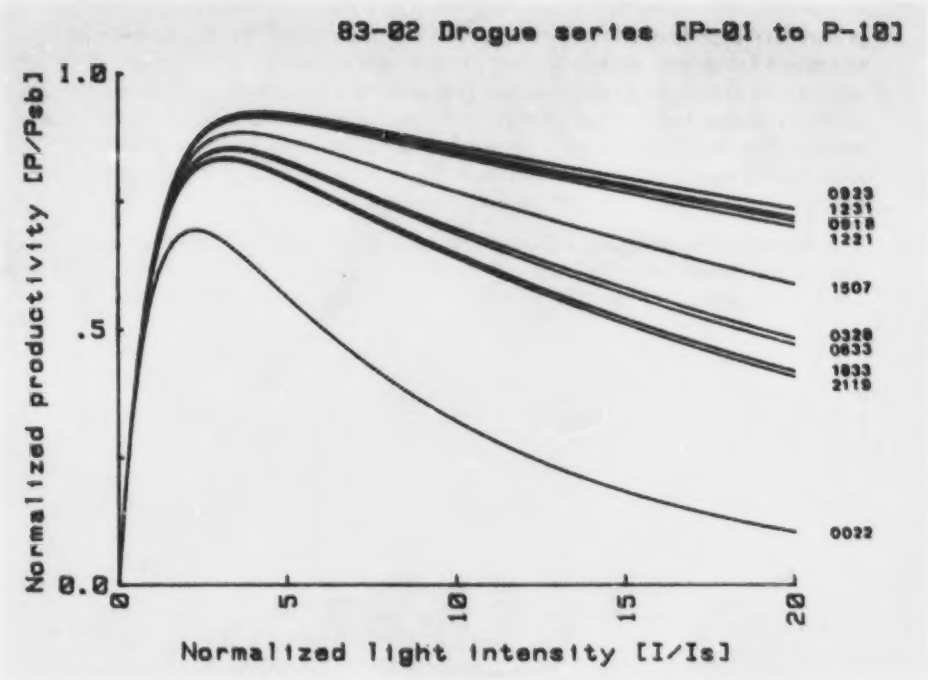
and 1979 possibly due to transient variables such as surface sea temperature and the onset of El Nino. These time-series were also de-trended by removal of components of fossil fuel $CO_2$ function and seasonal cycle sinusoidal function to establish natural variability with the aim of constructing a diagnostic model of Canadian atmospheric $CO_2$ to study the relationship of sources and sinks, i.e. the Canadian land forest and Arctic and ocean $CO_2$ reservoirs. *(Contact: C.S. Wong, Y. Chan.)*

# Ocean Ecology

## Plankton

In 1983 a study was initiated of the plankton ecosystems in Hecate Strait and Queen Charlotte Sound, an area where the biological oceanography is largely unknown. On a July cruise, high concentrations of phytoplankton and zooplankton were found over Cook Bank, at the north end of Vancouver Island. Data were highly variable with little pockets of low salinity water and with a strong physical and biological front in Queen Charlotte Strait separating stratified waters to the north from waters completely mixed from top to bottom by strong tidal currents in the narrow channels to the south. The shallow banks to the east of the Queen Charlotte Islands, important breeding grounds for many species of fish during late winter and spring, were thought to be barren of nutrients and phytoplankton during summer. However, a layer of phytoplankton living at a depth of about 20 metres that had escaped detection by previous near surface sampling from ships of opportunity was found. The finding is also noteworthy because it was thought that tidal mixing in this area would be so vigorous that phytoplankton would be evenly distributed from top to bottom. Apparently, fresh water input to the region is sufficient to supply a near surface layer of low salinity water that resists complete mixing by tidal currents. *(Contact: K. Denman, D. Mackas.)*

To answer questions that arise from the findings of biogeographical studies, such as the one outlined above, effort was focussed on studying certain individual processes in greater detail. From Ocean Ecology's four year field program off the southwest coast of Vancouver Island, the relationships between sample-to-sample resemblance and spatial separation for several different types of data (e.g. physical and chemical data, plankton biomass, the relative abundances of various species) was examined. Community structure, of both phytoplankton and zooplankton, was found to be similar over larger horizontal distances than total biomass concentration. The physical variables (temperature, salinity, and dynamic height) have a maximum dissimilarity around 30 kilometres, consistent with what one would find from random sampling of waves or eddies with scales of about 60 kilometres. This analysis will be extended to satellite imagery for the same areas. *(Contact: D. Mackas, K. Denman.)*



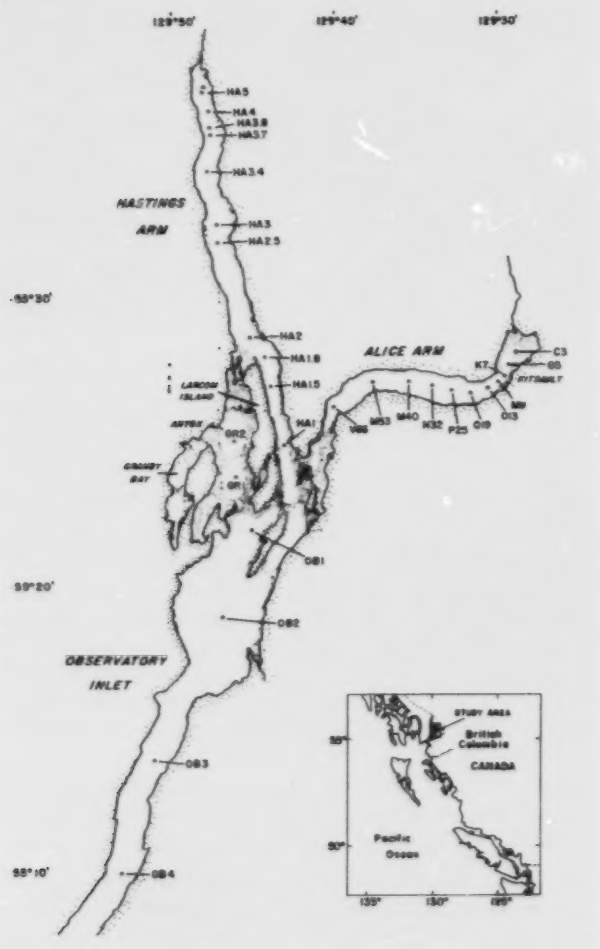

*Results from a 24-hour productivity versus light intensity (P(I)) experiment, illustrating diurnal variation in P(I) parameters. Note the increase in maximum photosynthetic rate and decrease in photoinhibition during the daytime hours. Sampling times (to the right of fitted curves) are in Local Apparent (solar) Time.*

To determine spatial changes in the photosynthetic rates of phytoplankton, the extent of the daily variations in these areas must be known. Accordingly, field experiments to investigate the response of natural populations of phytoplankton to varying light were performed on two cruises. Experiments involving repeated sampling of populations over 24-hour periods were carried out in Hecate and Georgia Straits and in Saanich Inlet. These experiments provided information on the daily variation in photosynthetic parameters defining the maximum light-saturated rate of photosynthesis, the rate of photochemical reactions, and susceptibility to photoinhibition. In addition to evaluating daily cycles in these variables, the results will also provide supporting data for models predicting the response of populations to varying light fields. *(Contact: R. Forbes.)*

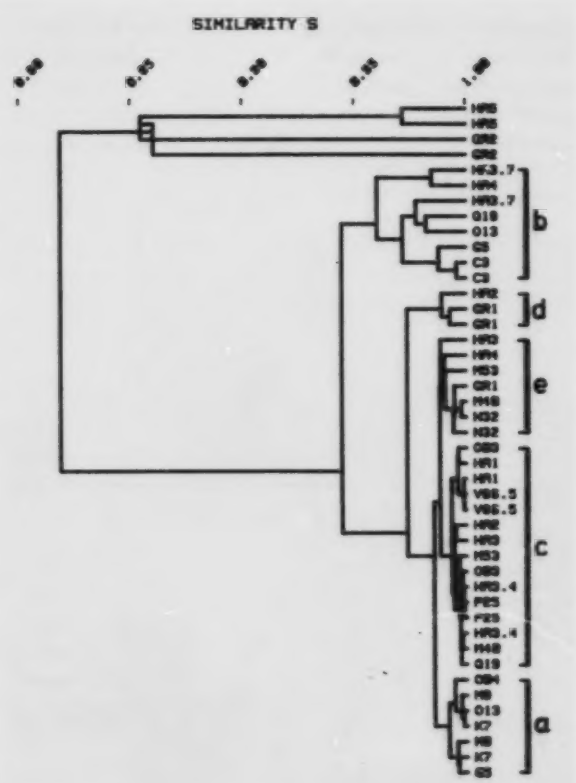
Progress was made on several smaller projects such as the development of phytoplankton cultures using chronoamperometry. This method will give an independent estimate of phytoplankton growth rates in the laboratory. A

preliminary experiment to test the feasibility of measuring the resuspension of sediments by bottom boundary-layer currents was successfully carried out. This experiment involved the simultaneous measurement of turbidity, photosynthetically-active irradiance and current velocity from a mooring at a fixed height above the bottom. The turbidostat system for use in laboratory phytoplankton growth experiments was completed and successfully underwent final testing. A paper describing the system is in preparation. *(Contact: S. Hill, K. Denman.)*

A five-year field program studying fine-scale (less than one kilometre) zooplankton pattern associated with the Fraser River plume in Georgia Strait was completed with a one-week cruise in May. The dominant zooplankton species *(Neocalanus plumchrus)*




*Map shows location of zooplankton community samples taken during cruises in August 1981 and June 1982. The mine tailings discharge is at Kitsault near station M9.*



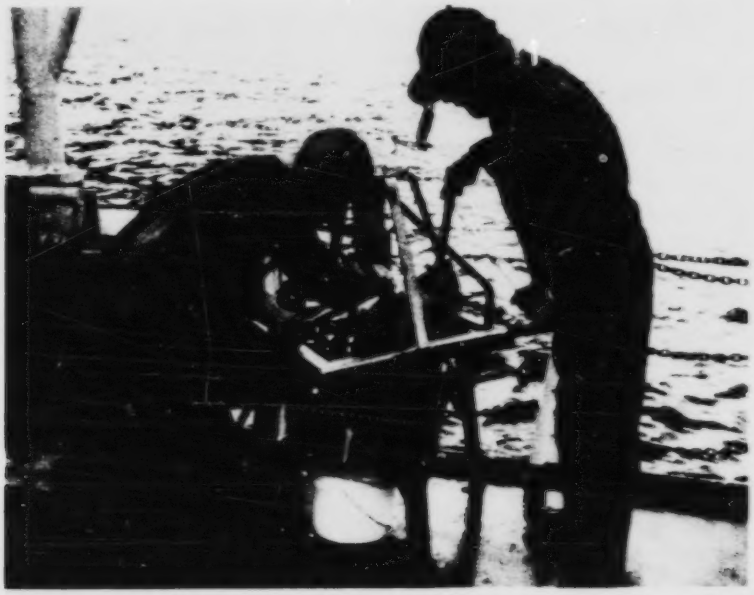

*The graph groups samples with similar species composition. The clusters of samples (based on their community structure) correspond closely with spatial segments of the inlet; for example, clusters "a" and "b" include the samples at the head of Alice Arm and closest to the tailings outfall.*

occurs in highest abundance around the outer margin of the brackish surface plume. The intensity of this aggregation varies both spatially and with tidal phase and appears to be associated with convergent circulation at the plume boundary.

Data collection for the ship-of-opportunity plankton sampling program was transferred to the Fisheries patrol vessel *Tanu*, which allowed both better spatial coverage and more reliable cruise scheduling. Existing underway sampling gear was installed on the *Tanu* with the addition of a winch for sub-surface sampling. Electronics hardware will be upgraded for the 1984 field season to allow sizing of the zooplankton. A workshop is planned for early 1984 to discuss the sampling program and its accumulated data base.

The analysis of small-scale zooplankton community pattern in the Alice Arm/Observatory Inlet system was completed and results were reported to the DFO's Amax Advisory Panel and submitted to a professional journal. Within each of two sampling periods, the overall range of compositional variability was small. However, statistical techniques such as cluster analysis showed that the highest similarity was between neighbouring samples and that differences in community composition were detectable between different regions of the inlet. Laboratory

studies of mortality, feeding, respiration and swimming behavior were continued in support of the field distribution studies. In general, the physiological impacts of suspended mine tailings (released at mid-depth near the head of Alice Arm) were also small but were consistent with the observed community pattern—species which were usually abundant at the head of Alice Arm were especially tolerant of high tailings exposure, while those with lower tolerance tended to have their highest abundance elsewhere in the inlet system. *(Contact: D. Mackas.)*



*Careful washing of samples collected in Alice Arm to assess the impact of mine tailings on the benthic community.*

## Benthos

The single most exciting event this year was the discovery of an active hydrothermal vent on the Juan de Fuca Ridge by a multi-agency expedition headed by Dr. V. Tunnicliffe, a former post-doctoral fellow of IOS, now on the faculty of the University of Victoria. IOS involvement included microbiological studies in these extraordinary environments. The bacteria obviously play a key role in these communities, in which the basic energy supply for support of life appears to be derived indirectly from the mineral-laden hot water emanating from the vents mediated via the bacteria rather than from sunlight energy through the normal process of photosynthesis. The large and colourful vent worms that characterize the faunas of these vents have no intestines, but instead harbour internal colonies of bacteria that have not so far been cultured outside their hosts. A great many

important biological studies need to be done on this site using *Pisces IV* to locate the site and deploy experiments.

Work on the microflora is related to studies of the anoxic/oxic interface of Saanich Inlet beside the Institute. Production by chemosynthetic bacteria at this interface is being assessed in terms of its significance to the production of plankton at the expense of the benthos in the inlet, which appears to rival the Black Sea as a natural laboratory for such studies. *(Contact: S.K. Juniper.)*

Analysis of the data from the continental shelf survey described in 1982 has been delayed but specimens have been distributed to experts for verification of identifications. The bulk of the routine material has been deposited with the National Museum of Natural Sciences in Ottawa. Extension of hydrocarbon exploration and possible exploitation will require much better knowledge of the fauna of the continental shelf in the foreseeable future. *(Contact: R.O. Brinkhurst.)*

The initial study of the benthos in Alice and Hastings Arms in connection with the deposition of mine tailings from the Amax mine at Kitsault was completed. Clear signs of impact of the tailings on the benthos along the deepest trench could be detected, and the already depressed fauna nearer the head end of the inlet (presumably affected by earlier industrial operations) was further reduced. A second set of samples was obtained in a joint Fisheries Management/IOS funded operation with cooperation from the Environmental Protection Service. These samples were obtained after deposition of tailings was halted, and so may reflect any toxic rather than physical burial effects on the fauna, or may show recolonization if any has occurred in the months since mine closure. The samples will be analyzed in early 1984. *(Contact: R.O. Brinkhurst.)*

In other activities, the distribution of squat lobsters *(Munida)* in Saanich Inlet continues to be monitored along with the oxygen profile using the oxygen probe and the CTD instrument purchased for this purpose. Continued support has been provided for the production of check lists, bibliographies and faunal guides to the benthos and planktonic forms such as mysids and euphausids. Work on aquatic oligochaetes included identification of verifications and educational services for the consulting community. Evolutionary concepts continued to provide focus for a number of efforts, including the use of computerized objective methods for taxonomic discrimination. Several new species and genera were described and a number of taxa were revised, including a revision of the fauna of Lake Baikal, a source of endemic species. All of the experimental toxicological work of recent years has now been published, and the results have been used to debate the efficacy of environmental management based largely on this laboratory approach rather than on such work coupled with good field ecology.

The grievous loss of Dr. H.R. Baker, who died suddenly while on a field excursion early in the year, was deeply felt by the laboratory in which he had worked so successfully. Considerable efforts have been made to complete his unfinished studies and to distribute his material to appropriate institutions.

# Ocean Information

Ocean Information activities support the management, protection and exploitation of marine resources. Primary responsibilities include the collection and dissemination of oceanographic research data, the conduct of marine climatological analyses, the evaluation of environmental reviews, and the provision of information and advice through various committees to regulatory agencies. The Division also oversees the regional ocean dumping research program, provides information to OSS clients, media and the general public, and provides policy and planning support for regional operations.

## Oceanographic Data and Climatological Services

Significant progress was achieved during 1983 towards compiling and appraising both Arctic and west coast oceanographic data sets. Four additional Arctic data set catalogues were published. These included physical oceanography for the Northwest Passage and Queen Elizabeth Islands, physical oceanography for Baffin Bay and Ellesmere Island and chemical oceanography for the Northwest Passage. A total of six volumes have been published to date; others covering Beaufort Sea fish, whales and zoobenthos and Canada Basin physical and chemical oceanography will be published in 1984.

The west coast data set catalogue for chemical oceanography of Queen Charlotte Sound, Hecate Strait and Dixon Entrance is progressing well and will be published in 1984 in conjunction with its physical oceanography counterpart. A preliminary compilation of all west coast physical and chemical data sets, without appraisal, for Georgia and Juan de Fuca Straits and for offshore waters will also be published in 1984. Also scheduled for 1984 publication are a review of west coast atlases, marine environmental assessments and data reports focussing on currents, winds, herring, shellfish and marine mammals.

Emphasis continued to be placed on the appraisal of the quality of data sets. This has contributed to the establishment of data archiving priorities in conjunction with the Marine Environmental Data Service (MEDS) and resulted in the highest quality Beaufort Sea physical and chemical marine data being archived in the GF-3 format. Some success has been achieved in devising suitable data set rating criteria for marine biology.

Data set catalogues have been distributed to approximately 300 private and public sector users. An interactive computer data base was instituted to permit quick sort and retrieval of data sets by time, space, quality and discipline. Several other reviews and analyses were completed or near completion in 1983. These include *A Comparison*

*of Natural and Petroleum Resource Development Related Fluxes of Metals, Hydrocarbons and Nitrogen, Phosphorus and Silicon to the Beaufort Sea; Weather, Ice and Sea Conditions Relative to Arctic Marine Transportation* (jointly with AES) and *A Historical Review of Marine Dredging. (Contact: A.B. Cornford, B.D. Smiley.)*

During 1983 the B.C. Shorestation Oceanographic Program (lighthouse monitoring program) supplied surface seawater temperature and salinity data from 18 locations. At "open ocean" sites, such as Amphitrite Point and Langara Island, the anomalies in sea surface temperature increased abruptly through December 1982 and January 1983, reached a maximum between March and May 1983, and in general decreased thereafter. Maximum anomalies were between two and three times the standard deviations from the long-term mean. This surface warming appears to be one mid-latitude manifestation of the 1982-83 major El Nino event. *(Contact: L.F. Giovando.)*

*Video graphics terminal used for accessing Ocean Information data bases. Work station includes dot matrix printer and a graphics plotter.*

## Environmental Services

IOS continued to give substantial support to the Arctic Waters Advisory Committee (AWAC) and the Arctic Regional Ocean Dumping Advisory Committee (RODAC) in reviewing offshore oil and gas activities, oil spill contingency plans, regulatory requirements and dredging/dumping proposals. Formal reviews were undertaken for west coast RODAC and considerable advice was given regarding the dredging of False Creek in Vancouver. *(Contact: A.B. Cornford.)*

Scientists at IOS undertook a very detailed technical review of both the Beaufort Sea Environmental Impact Statement (EIS) and its Supplement, and Ocean Information Division made substantial contributions to the EARP public hearings at Inuvik and to the DFO position paper. Reviews of several major initiatives—a CMO

proposal to drill for oil in Lancaster Sound, proposed port developments at King Point and Stokes Point, and the Beaufort Sea Environmental Monitoring Project (BEMP)—were completed on behalf of the Department of Indian Affairs and Northern Development (DIAND). *(Contact: B.D. Smiley.)*

Detailed reviews of Initial Environmental Evaluations (IEEs) prepared by Petro-Canada and Chevron Canada relating to proposed offshore drilling in Canadian west coast waters contributed to a workshop sponsored by the Canadian Oil and Gas Lands Administration (COGLA) and the B.C. Ministry of Energy, Mines and Petroleum Resources. A departmental technical submission and position statement will be prepared for a joint federal-provincial Data Forum established to assist a formal public review process scheduled for 1984. *(Contact: L.F. Giovando.)*

## Ocean Dumping

IOS administers the Ocean Dumping Control Act research fund for both western Arctic and Pacific marine waters. Research results are reviewed and published in the proceedings of an annual workshop. The Institute also serves in an advisory capacity regarding all marine dredging and dumping permits issued by DOE's Environmental Protection Service. Emphasis in 1983 centred around disposal options for False Creek and Alberni Inlet dredge spoils, while 1984 will focus upon a protocol for reporting accurate and precise data. *(Contact: L.F. Giovando.)*

## Information and Media Relations

The third in a new series of IOS Annual Reviews was completed along with contributions to various publications including departmental and inter-departmental annual reports. Updates of Institute research activity and other noteworthy events were combined in a monthly report for the OSS Assistant Deputy Minister. Articles covering various facets of IOS works were placed in various trade and special interest publications.

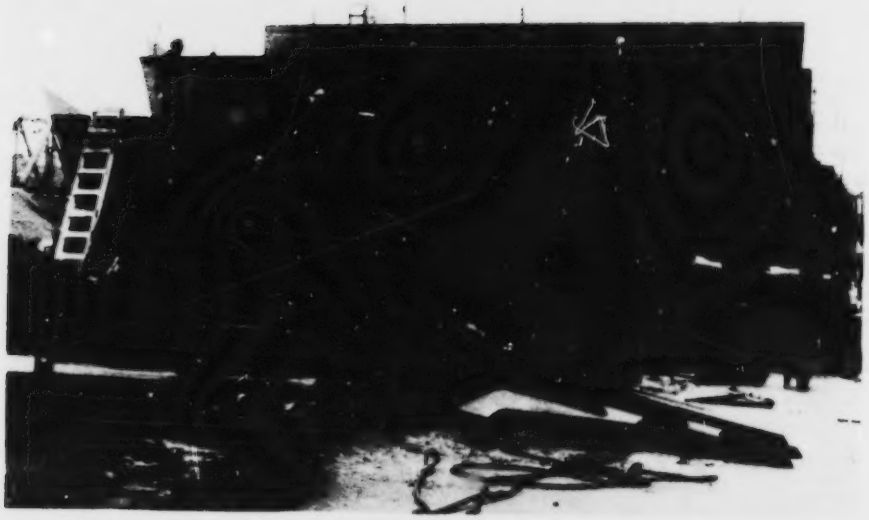
IOS set up several temporary displays in B.C. in 1983 including "From Leadline to Laser", marking the centennial of the Canadian Hydrographic Service and provided extensive media liaison for events such as the historic *Pisces IV* dives to offshore Juan de Fuca Ridge hot vents.

Preparations have begun for participants in the Canada Pavilion at the 1984 Pacific National Exhibition and discussions have taken place regarding IOS involvement at Expo '86. *(Contact: K. Glover.)*

## Policy/Program Analysis

A major review of departmental planning included a Review of Estimates exercise, a new Operational Planning Framework and reworked objectives, a Multiyear Operational Plan (MYOP), a Summary Operational Plan, Work Plans and a Program Review and Evaluation (PRE). A major audit of the physical oceanography program was undertaken by the Audit and Evaluation Branch, Ottawa and progress reports covering IOS activities were submitted to the Office of Energy Research and Development (OERD).

# Ships



*Currently under construction at Bel-Aire Shipyard Ltd. in North Vancouver, a new oceanographic and hydrographic ship for IOS.*

**Pisces IV** *submersible*

# Ships

The Pacific Region Ship Division provided ship, submersible, launch and depot support for the 1983 scientific and hydrographic programs of the Institute of Ocean Sciences, the Pacific Geoscience Centre (PGC), universities and other federal agencies.

Of extreme importance in 1983 was the contract award for the construction of a 69-metre vessel to replace the *CSS Wm. J. Stewart*. This new vessel, expected to be in service in 1985, will not only add another dimension to the IOS fleet but will go a long way towards relieving the excess demand for existing vessels.

*CSS PARIZEAU* (64.3 m overall; 1929 tonnes)
*Master:* A.G. Chamberlain *Chief Engineer:* P. Pereira

The mid-life refit was completed successfully. The new arrangements for accommodation and the re-engining of the vessel have been major contributors to increased efficiency.

*CSS Parizeau* resumed service as a primary Search and Rescue (SAR) vessel for the herring roe fishing fleet. For the remainder of the year the ship was employed in support of scientific programs involving Ocean Physics, Tidal and Current Surveys, Ocean Chemistry, EPS, Department of National Defence, PGC and the University of British Columbia (UBC).

*CSS VECTOR* (39.6 m overall; 505 tonnes)
*Master:* R.W. MacKenzie *Chief Engineer:* R. Pearson

*CSS Vector* provided support for the scientific programs of Ocean Physics, Ocean Chemistry, Ocean Ecology, EPS and UBC.

*CSS RICHARDSON* (19.8 m overall; 78 tonnes)
Master: (Acting) J. Campbell/A.S. Coombes

*CSS Richardson* was used by the Hydrographic Division in field surveys in the Quatsino Sound and Ridley Island areas. *Richardson* also spent several weeks on SAR duties during the herring roe season.

*M.V. PANDORA II* on charter (58.2 m overall; 1220 tonnes)
*Master:* S. Gulati *Chief Engineer:* R. Rogers

The *Pandora II* was employed in support of scientific programs involving Ocean Ecology, EPS, Pacific Biology Station, Simon Fraser University, UBC and University of Victoria. The majority of these programs were in conjunction with the submersible *Pisces IV*.

*PISCES IV:* (6.1 m overall; 12 tonnes)
*Chief Pilot:* F. Chambers

At the beginning of 1983, the submersible *Pisces IV* was transported by a Canadian Armed Forces Hercules aircraft to the Naval Ship Research and Development Centre at Annapolis, Maryland. The *Pisces IV* was fitted to a special cradle and placed in a pressure chamber where a test pressure of 3200 p.s.i. was applied. This is the simulated equivalent of 2000 metres, the depth to which the *Pisces IV* is now certified to dive. On her return to IOS, in conjunction with the mothership, M.V. *Pandora II, Pisces IV* was employed in support of Ocean Ecology, University of Victoria, Simon Fraser University, Dept. of National Defence, Pacific Biological Station and EPS.

Barge *PENDER*

The *Pender* was used as mothership by the *Pisces IV* early in the year and later was used extensively by the Hydrographic Division in support of field surveys in the Gunboat Channel, Spiller Channel and Milbanke Sound areas.

## Institute Workshops

The Depot staff were responsible for the repair and maintenance of the Institute's fleet of over 30 launches and small boats as well as providing support for the *Parizeau, Vector* and *Richardson.* Mechanics were supplied to the *Pender* and *Polar Circle* during their hydrographic service and depot personnel were also involved in the development and testing of scientific equipment such as the Active Drifter and the Stern Tow.

## Deck Machinery

Deck Machinery staff were responsible for the ongoing maintenance of winches and support gear for the various scientific cruises. Service was also provided in the fitting out of the charter vessel *M.V. Polar Circle* for its hydrographic duties in the Arctic.

# Management Services

# Management Services

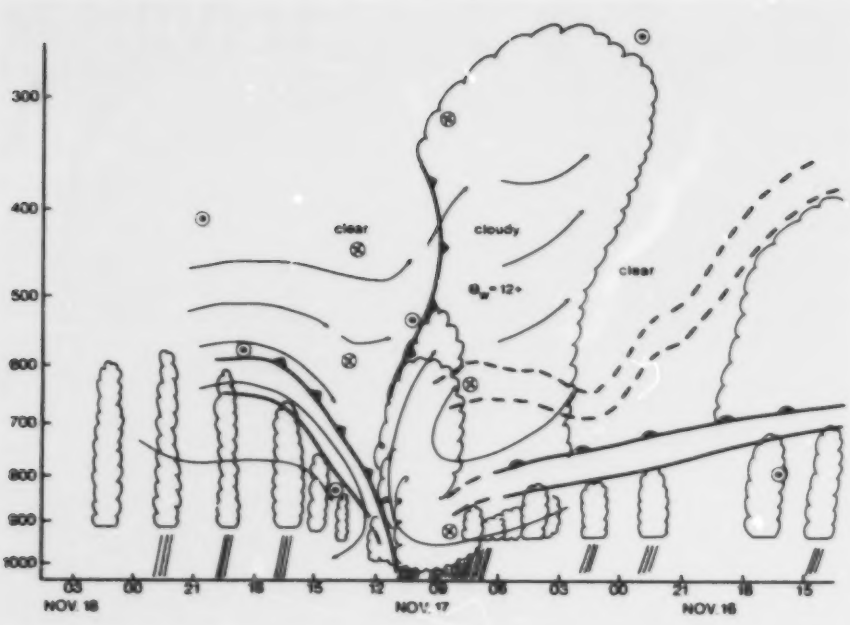
In 1983 continued emphasis was placed on increasing productivity, reducing the paper burden and using current technology in performing administrative functions.

User requirements were drawn up for a system called AIMS (Automated Integrated Management System) which is designed to use a regional computer base and intelligent desk top terminals to perform some of the basic tasks in a logical sequential work-processing flow. These tasks include purchasing, expenditure and commitment control, accounts payable and receivable, fixed asset and equipment distribution, person-year control. A proposal was made to departmental headquarters to fund two pilot systms for AIMS, one at IOS and one in Fisheries Management, Pacific Region. A significant feature of the proposal is that the design and commissioning of the system will involve the Central Accounting Branch of the Department of Supply and Services.

The energy conservation program was active again in 1983. Double glazing of the main building was completed and improvements were made to the heating and ventilation system. In terms of cost, the largest job undertaken for energy conservation purposes was the insulation of the hangar building. Electric heating and double-glazed windows were also installed. Two more vehicles were converted to propane use.

The library received two large gift collections which are gradually being incorporated. These will substantially enhance the collections in the areas of meteorology and in oceanographic journals. The Institute's librarian was elected chairman of the Council of Fisheries and Oceans' Librarians for the upcoming term.

# DEPARTMENT OF THE ENVIRONMENT




*Vertical cross-section through weather front over the ocean. The warm and cold fronts are indicated by heavy lines. The arrows indicate air motions. Crosses and dots indicate air motions away from and towards the reader. Clouds and rain are shown schematically.*

# Atmospheric Environment Service

## Atmosphere-Ocean Interaction

Studies have continued of storms over the northeast Pacific Ocean. Warm and cold frontal systems are usually associated with precipitation and major changes in weather conditions. By using weather radar and balloon-borne instrument packages, launched from a ship, the structure of such a system has been extensively investigated. Bands of cloud elements were found to move with the cold front, providing most of the heavy precipitation. The rain associated with the warm front was more widespread, and continuous but of lighter intensity. A schematic cross section of the storm shows the gently sloping warm front and much steeper cold front. The cloud area aloft is fed mainly by moist, warm air moving up near the cold front. As the system moves easterly, warm, moist air from the south moves northward in advance of the cold front and then rises. As it rises it mixes with faster moving air aloft and moves eastward. For this case, this stronger winds aloft have created an upper front which is separate from the surface feature. After frontal passage, the air is cooler aloft and warmed by the ocean surface, creating convective showers. Further understanding of these types of storm systems will lead to an enhanced ability to model and predict weather systems arriving at the Pacific coast.

Atmosphere-ocean exchanges of heat play a major role in determining the earth's climate. An historical data set for the North Pacific Ocean, covering over 25 years, has been examined to determine the spatial and temporal variations in the monthly averaged heat flux. There is, as expected, a large annual cycle but this cycle is quite different from year to year. The inter-annual variability also differed for various areas of the ocean basin. This variability is related to the variations in the oceanic heat transport. Studies have begun to investigate this relationship. Two different TransPacific sections of deep hydrographic stations are being investigated and a measure of the variability determined. *(Contact: G.A. McBean.)*

## Precipitation Chemistry on the Pacific Coast

Collection and analysis of rain and snow samples at IOS, on ships and at Mount Washington continued. Analysis of the snow core samples, collected jointly with Pacific Region, AES, Vancouver, has allowed the mapping of the precipitation chemistry in the southwestern coastal region. Since the pH of "clean" precipitation in

equilibrium with atmospheric $CO_2$ is 5.6, only the snow in areas near Georgia Strait/Vancouver is significantly depressed due to contributions from sulphuric and nitric acids. On Vancouver Island and the interior region the sulphate values were generally below the detectability levels of the analytical procedures used. These results indicate that the long-term measurements taken at Vancouver are probably representative for the Georgia Strait/Vancouver area but not for more distant locations. *(Contact: G.A. McBean.)*

# Canadian Wildlife Service

Field studies in the Queen Charlotte Islands continued in 1983 on two seabird species, the Ancient Murrelet and the Cassin's Auklet, both of which dive for their food. In addition, a research program was initiated on Fork-tailed and Leach's Storm-Petrels, which do not dive, but dip in surface waters to forage on amphipods, jelly fishes and fishes. Both species nest on small offshore, wooded islands in the Queen Charlotte Islands. Their feeding habits differ in that the Leach's Storm-Petrel feeds predominantly in warm waters beyond the continental shelf, while the Fork-tailed Storm-Petrel forages mostly over colder shelf waters in summer and fall. The Fork-tailed Storm-Petrel nests from April until the end of September, and the Leach's Storm-Petrel, the latest nesting seabird on the B.C. coast, from June until the beginning of November. Both storm-petrel species lay a single egg each at the end of a nesting burrow in the soil. The young storm-petrels spend two months in their burrows before they are able to fly; a much longer nestling period than that for any other seabird in British Columbia.

*Fork-tailed Storm Petrel*

The distribution of the two storm-petrels was also investigated at sea during IOS cruises in Hecate Strait, Queen Charlotte Sound and on the west coast of the Queen Charlotte Islands. Those cruises not only provided information on storm-petrels but also on the distribution and populations of other pelagic seabirds. The most numerous species observed on the sea cruises were Sooty Shearwaters, which are pursuit divers and which nest in the southern Pacific and visit B.C. waters during our summer. Millions of shearwaters pass through Hecate Strait and Queen Charlotte Sound in May and it is not uncommon to see feeding flocks numbering 50,000 to 100,000 birds.

The information on pelagic seabird distribution and populations will be valuable in obtaining a first glimpse of the importance of the seabird resource on the continental shelf. Of all resources, seabirds are most at risk from oil spills. Oil companies have now made applications to conduct exploratory drilling for oil and gas. The present moratorium for offshore drilling may be lifted for Shelf waters between southern Alaska and northern Vancouver Island. It is precisely there, and not in the Straits of Georgia and Juan de Fuca, that there are unique and almost pristine populations of seabirds which Canadians are just beginning to enjoy. It is therefore essential that a thorough investigation of this resource is conducted before the moratorium is lifted. *(Contact: K. Vermeer.)*

# DEPARTMENT OF ENERGY, MINES AND RESOURCES

## Pacific Geoscience Centre

Pacific
Geoscience
Centre

# Geological Survey of Canada and Earth Physics Branch ○○○

## Director's Foreword

Many new developments occurred at the Pacific Geoscience Centre (PGC) during 1983 in a broad range of disciplines including the geology of the continental margin and adjacent offshore, marine geophysics and geophysical studies of the Cordillera. Specifically these studies include fjord, estuarine and deltaic sedimentation and structure, coastal sedimentary processes, micropalaeontology and related geological field mapping, palaeomagnetism, geomagnetic studies, gravity, geodynamics, seismicity, geothermal energy and plate tectonic interactions.

A notable development was the much expanded Juan de Fuca Ridge study which included extensive SEABEAM and SEAMARC II high resolution bathymetry and acoustic images. This research was undertaken in cooperation with NOAA, the University of Hawaii and Canadian Hydrographic Service. The results of these investigations along with the multiparameter resource charting activities in the area, provide an essential background for detailed ship and submersible studies of ridge hydrothermal processes and related sulphide mineralization.

Renewed interest in offshore petroleum exploration has provided an impetus towards a better understanding of the character and structure of the offshore sedimentary basins. As a result, new studies have been initiated in the Queen Charlotte Sound and Hecate Strait areas (Queen Charlotte Basin). These include the nature of the seafloor sediments and particularly their stability in the event of earthquake activity, structure of the basinal sediments and their geological history. Equivalent rock units of Jurassic, Cretaceous and Tertiary age are under intensive study on the adjacent Queen Charlotte Islands. Petroleum exploration has also spurred PGC earthquake monitoring in the Beaufort Sea and on the Grand Banks of Newfoundland.

A very successful meeting of the GAC/CGU/MAC was held at the University of Victoria in May. Much of the organization was carried out by geologists of PGC and the B.C. Department of Energy, Mines and Petroleum Resources to whom hearty congratulations are extended.

Two new developments will have significant future impact on PGC activities. An agreement between EMR and NSERC on behalf of a number of universities paved the way for a continuing major program of deep crustal studies in Canada (LITHOPROBE). The investigations will employ seismic techniques as well as a wide range of other geological and geophysical disciplines. The first profile will be across Vancouver Island in 1984. The second important development was the steps taken

for Canada to become a member of the next phase of the international Deep Sea Drilling Project (DSDP). This project will undoubtedly involve many PGC scientists and should result in eventual drilling of deep sea holes in the Juan de Fuca Ridge area.

The Pacific Geoscience Centre had an extremely productive year, and it is to the credit of an outstanding staff that our organization is gaining recognition worldwide. *(R.D. Hyndman.)*

# Sedimentology

## Estuarine and Marine Delta Sedimentation

As in previous years demand remained high for geological data from the Fraser River Delta to help formulate environmental/engineering guidelines. Results of geological research have been applied to investigations by outside agencies relating to the proposed Iona Island sewage pipeline, Westshore Terminals coal port expansion and the B.C. Hydro proposal for a Vancouver Island gas pipeline. In addition, this year a demand arose for sedimentological information regarding potential new anchoring sites for large freighters in the Prince Rupert/Skeena Delta/Chatham Sound area.

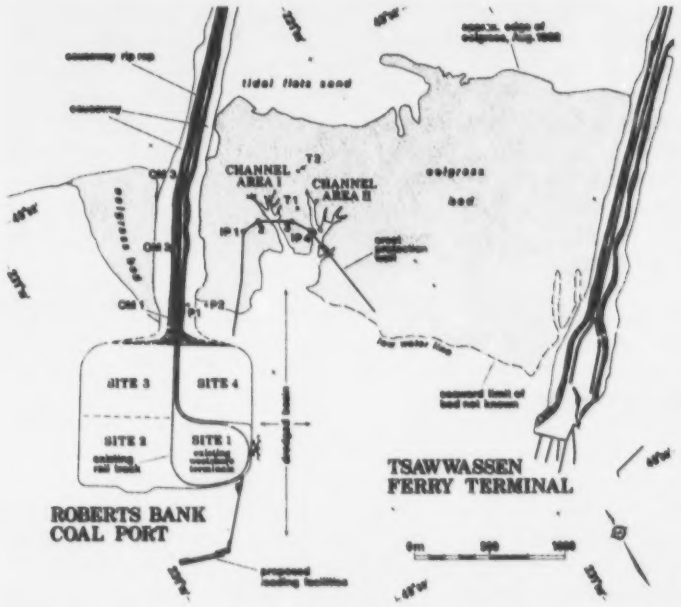
The highlight of the summer's field activities was the surveying, mapping and assessment of mechanisms influencing tidal creek erosion adjacent to the Roberts Bank Coal Port on the Fraser River Delta. Work was performed in association with students from the Engineering (Geological) Department of U.B.C. and Engineering Technology Department at the British Columbia Institute of Technology. *(Contract: J. Luternauer.)*

## Continental Shelf Sedimentation

Research proceeded on the mapping of the heavy mineral, lime, gravel and sand deposits in Queen Charlotte Sound, employing side-scan sonar and a vibracorer. This study will be coupled with a forthcoming survey of local geological hazards to development.

Preliminary lithologic descriptions were completed, enclosed shell matter was submitted for radiocarbon dating, and a preliminary assessment of the environments of deposition was undertaken with the assistance of Marine Geology and Geophysics

Section of cores (the longest of which is 8 m) collected during the *Hudson 81* cruise in Queen Charlotte Sound. These cores offer the longest continuous record of late Quaternary sedimentation available for the continental shelf of western Canada. *(Contact: J. Luternauer.)*




*Dendritic creek erosion at the head of dredged ship basin adjacent to Roberts Bank Coalport, Fraser River Delta. The creeks have eroded into an ecologically valuable eelgrass bed in response to the focusing of ebb tidal flow into the ship basin. The crest protection wall was erected to inhibit further erosion by slowing seaward water flow and trapping sediment. OM, IP represent survey markers; T represents navigation towers.*

## Coastal and Sedimentological Studies

Research focussed on the effects of sediment transport on grain size distributions. A simple model was developed to demonstrate that sediment in transport must become progressively finer and more negatively skewed whereas sediment remaining (a lag) must become coarser and more positively skewed than its source. Successive deposits derived from sediment in transport can become coarser or finer in the direction of transport with the skewness becoming more positive or more negative respectively. By comparing the relative changes in grain size distributions from deposits of a variety of environments (i.e. beach, nearshore or shelf) a pattern of sediment transport can be predicted.

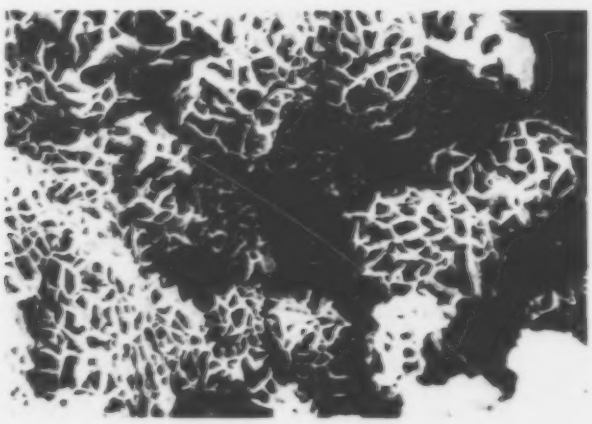
In this way the sediments have, in fact, integrated over time all the processes responsible for their erosion, transport and deposition. Given the high cost for

certain process studies, this kind of analysis is both relatively inexpensive and rapid. The sediment transport model has proven effective in predicting the pattern of oil movement in the coastal zone and may be a useful method in determining the fate of hazardous waste, heavy mineral concentrations and the location of placer deposits. *(Contact: P. McLaren.)*

Coastal mapping for the purposes of oil spill contingency planning was continued on the Queen Charlotte Islands. The program was designed to collect baseline data on the sedimentology and geomorphology of the shoreline. In a joint program with Petro-Canada, all "mappable" variables are treated independently and stored in a mini-computer system which enables future manipulation to obtain the most meaningful map units. Each variable can be correlated with any or all of the others to determine their spatial relationships and their possible interdependence. In this way, maps can be produced easily to serve a variety of purposes; for example, user-specific data maps for oil spill contingency planning or shoreline development as well as fundamental coastal research. *(Contact: P. McLaren.)*

## Marine Sedimentology

A one year assignment at the Centre de Recherches de Sédimentologie Marine, Université de Perpignan, France, was completed in August, 1983. During this period a study of the nature, genesis and distribution of glauconie on the Vancouver Island continental shelf was undertaken with Pierre Giresse using microprobe, atomic absorption spectrophotometry, x-ray diffractometry and light microscopy. Glauconie is a family of green authigenic iron- and potassium-rich clay minerals. After returning to PGC, further studies of glauconie were completed with GSC support using scanning electron microscopy. *(Contact: B.D. Bornhold.)*



*Boxwork form of authigenic glauconie from the Vancouver Island continental shelf.*

*Pillow lavas and thin covering of sediment. Dellwood Knolls.*

A detailed morphological synthesis of the 1975 submarine landslide in Kitimat Arm was completed in conjunction with the Coastal Studies Institute at Louisiana State University. The analysis includes a partial side-scan sonar mosaic of the area, a map of surface topographic features, the 1952 and 1981 bathymetries, a map of bathymetric change due to landslide events, computer drawn block diagrams of the pre- and post-slide bathymetries, and a block diagram of the principal morphological elements of the slide.

In September a successful cruise of *CFAV Endeavour* was undertaken in cooperation with Henri Maillot and Bertrand Blaise of the University of Lille (France). During the cruise 26 sediment cores, deep sea photographs and water temperature measurements at 10 sites, and several hundred kilometres of continuous high resolution seismic profiles were obtained in the vicinity of the Dellwood Knolls. Mineralogical and chemical studies are being carried out by scientists at Lille. *(Contact: B. Bornhold.)*

## Sedimentology Laboratory/Data Section

The sedimentology laboratory provides technical and analytical support for the marine geology subdivision. The primary activities are aiding in the collection of soft sediment samples, describing them and carrying out grain size analyses. The samples, taken by bottom grabs, cores and dredges, are collected from coastal, estuarine, deltaic, continental shelf and continental slope environments. Grain size is determined using sieves for gravels, a settling tube for sands and a sedigraph for the mud fractions. About 1000 grain size analyses were processed throughout the year.

The data section of the sedimentology laboratory maintains an inventory of samples collected or donated. (The current total is in excess of 7500.) It is also

responsible for the archiving of those samples as well as handling requests for data and subsamples. Six groups outside of the Pacific Geoscience Centre contributed samples in the past year and twenty requested data and/or sub-samples. *(Contact: T. Forbes.)*

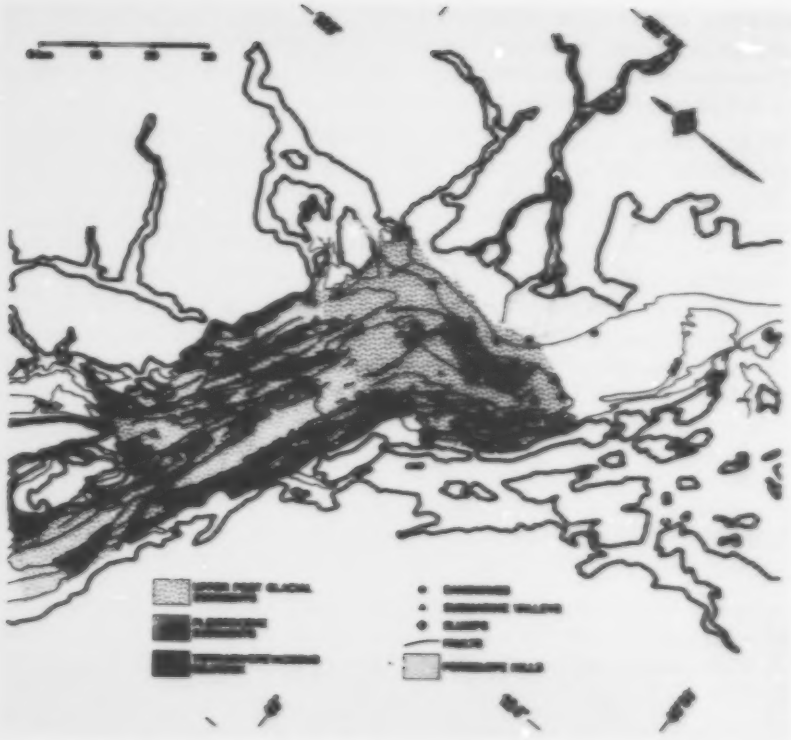
# ○○○○ Marine Geology and Geophysics of Georgia Strait

Geological, geophysical and geotechnical information on the Strait of Georgia is currently in high demand apropos of the proposed natural gas pipeline crossings, spoils dumping schemes, site specific surveys and various academic projects. New data to meet these needs were collected during 1982 and 1983 in a series of 5 cruises aboard the *CSS Vector* and *CFAV Endeavour*. Investigations include both Canadian and American portions of the Strait. The data base currently under analysis includes over 2000 km of seismic and high resolution sub-bottom profile lines, magnetometer and sidescan tows and over 60 cores (gravity and vibracore samples) from the Quaternary to Recent unconsolidated sediments. The overall purpose of these investigations is to understand better the geological history from the sedimentary and seismic records and to present the data for public use. Of particular interest is the widespread distribution of features suggesting seafloor instability; chiefly faults, slumps and submarine slides. Cooperation with private industry, academic institutions and other government departments has been high. *(Contact: T.S. Hamilton.)*

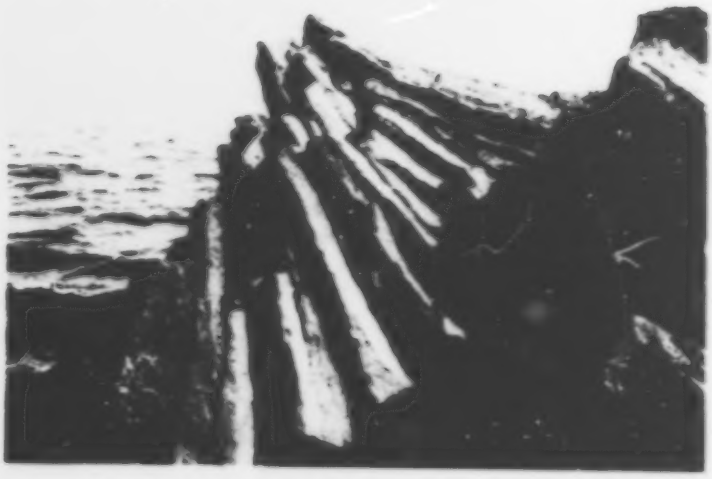
## Bedrock Studies — Continental Margin

A start was made on a study of the basin evolution of the Georgia Depression in terms of its association with Cretaceous and Tertiary plate tectonic processes affecting the continental margin. Its identification as a back-arc or fore-arc basin is unclear; there are arguments to support both origins. Detailed stratigraphic and sedimentological studies in association with paleobathymetric analyses based upon Foraminifera will be applied to regional facies distributions so as to delineate shallow and deep depocentres. Detailed sampling for porosity and vitrinite reflectance, as well as for thermal conductivity determinations was begun. This work will provide information on the basin's subsidence and thermal history. Several industrial multichannel seismic lines were examined for preliminary structural control beneath the basin. The Tertiary section encountered in the three Atlantic Richfield wells on the lower mainland were examined. *(Contact: C.J. Yorath.)*

Renewed interest in hydrocarbon exploration both on and offshore in the Queen Charlotte Islands, and a keen international interest in the Juan de Fuca Ridge system,



*Map showing Quaternary geology of Georgia Strait*



*Polygonal jointing in a Basaltic Volcanic Neck, Skaga Is.*

require a better understanding of various volcanic rock units in the Insular Belt and offshore regions adjacent to western Canada. Understanding the origin of the volcanics erupted in a given environment is essential to comprehending the evolving tectonics and deep seated geological processes.

The Tertiary Masset Formation, well represented in the Queen Charlotte Islands and nearby offshore, has abundant basic and sialic lavas with hydrocarbon shows. Petrographic, petrochemical, isotopic and paleomagnetic studies are underway to help elucidate the genesis of the lavas and to discern their subsequent tectonic motions. The volcanic rocks of the Jurassic Yakoun Formation are the subject of similar studies which will help to constrain the models for earlier parts of the geologic column. Preliminary investigations have also been made of the Tertiary Metchosin and Alert Bay volcanics on Vancouver Island, and of the submarine lavas of the modern day triple junction at the northern end of the Juan de Fuca Ridge (Dellwood Knolls and J. Tuzo Wilson Knolls). *(Contact: T.S. Hamilton.)*

## Technical Services

Technical Services provides electronic and mechanical engineering support for the Marine Geology and Geophysics group, and the Paleomagnetic Laboratory. The main thrust is in the maintenance and operation of scientific equipment and upgrading of existing equipment.

Two hydrophone arrays with built-in preamplifiers were designed and built for shallow continuous seismic reflection profiling to improve an analogue seismic data acquisition system for the Quaternary geology of Georgia Strait project. A feasibility study and purchase of a multichannel digital seismic system to replace two single channel digital systems was undertaken. The system will be capable of digitizing six channels of data up to 1 kHz and one channel of 3.5 kHz.

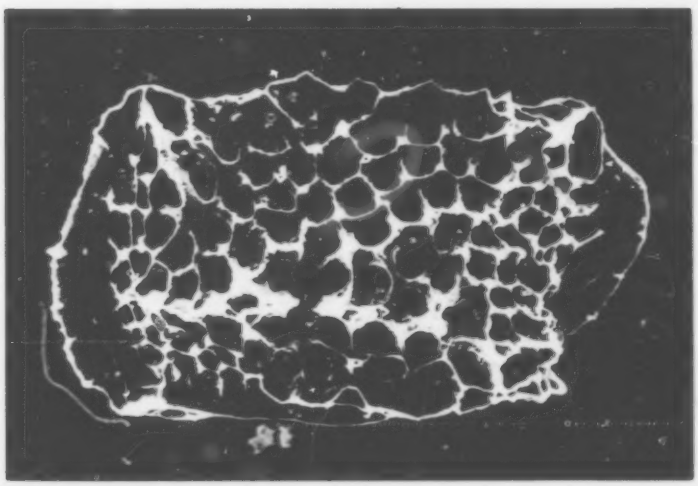
The rock magnetic properties laboratory was completed and the paleomagnetic laboratory acquired an IBM personal computer in preparation for the next step in the automation of data processing. *(Contact: I. Frydecky, W. Hill.)*

During 1983 technological and operational improvements included the purchase of a high pressure air compressor (150 scfm). In marine seismic studies it allows for refraction profiling in conjunction with the University of British Columbia's large air gun (2000 cu. in.), as well as upgrading our reflection profiling capabilities with the 300 cu. in. air gun in the offshore regions. With new heavier coring equipment (2000 lbs.), cores of unconsolidated sediments can be taken up to 12 metres in length. Use of an Emerson-MacIntyre vibracore from the Atlantic Geoscience Centre enabled core sampling in sandy areas in Queen Charlotte Sound and the Strait of Georgia, which were not previously obtainable. Modifications to our dredging gear include the use of teeth on box dredges for greater sample recovery and net liners to preserve fragile samples. *(Contact: G. Jewsbury.)*

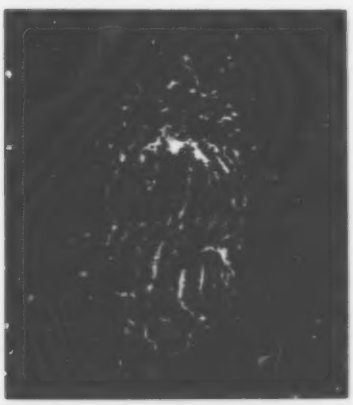
# Palaeontology

Activities in micropalaeontology and biostratigraphy at PGC cover a broad spectrum of investigations in rocks ranging in age from Jurassic to Quaternary from both subaerial exposures and offshore localities. Studies in the biostratigraphy of the Jurassic and Cretaceous rocks of the Queen Charlotte Islands are continuing. This topic deals with correlating the various rock units principally by the use of foraminifers and mapping their distribution and tectonic history. Observations as to their petroleum source bed potential and hydrocarbon shows have also been made.

Studies in Late Quaternary sedimentation and stratigraphy are being aided by extensive use of ostracod biofacies investigations on the continental shelf, the Georgia Strait and the deep sea. The largely undescribed ostracod populations of the west coast have been found to be excellent environmental indicators and as well suggest sources of the enclosing sediment and explain sedimentary distributional patterns. Excellent, and in some cases, unusual ostracodal and foraminiferal populations have been recovered from cores around the deep sea spreading ridges. The purpose of this study is to investigate the possibility that the occurrence and distribution of some of these forms is at all related to thermal vents. *(Contact: B.E.B. Cameron, M. Johns.)*



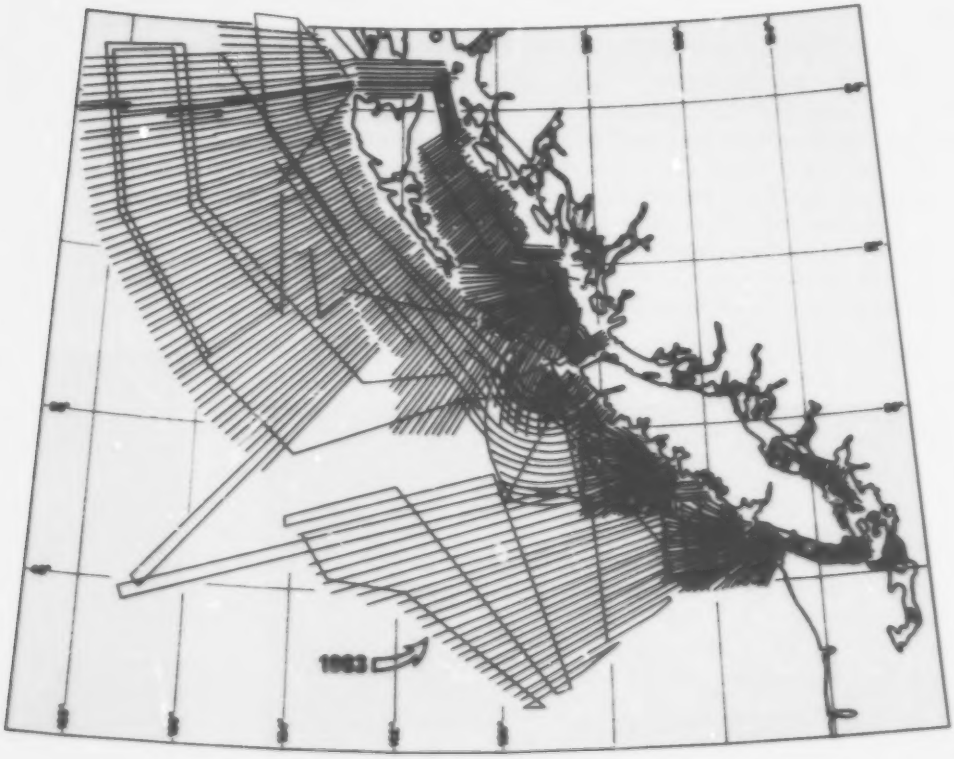
*Deep sea ostracod* Encytherura *sp.*



*Aberrant foraminefera* Uvigerina dirupta. *Note doubling of terminal principal aperture.*

# Multiparameter-Geophysical Surveys

Systematic magnetic, gravity and bathymetric surveys are being conducted over the Canadian Economic Zone to help assess the economic potential of the region and its tectonic framework.



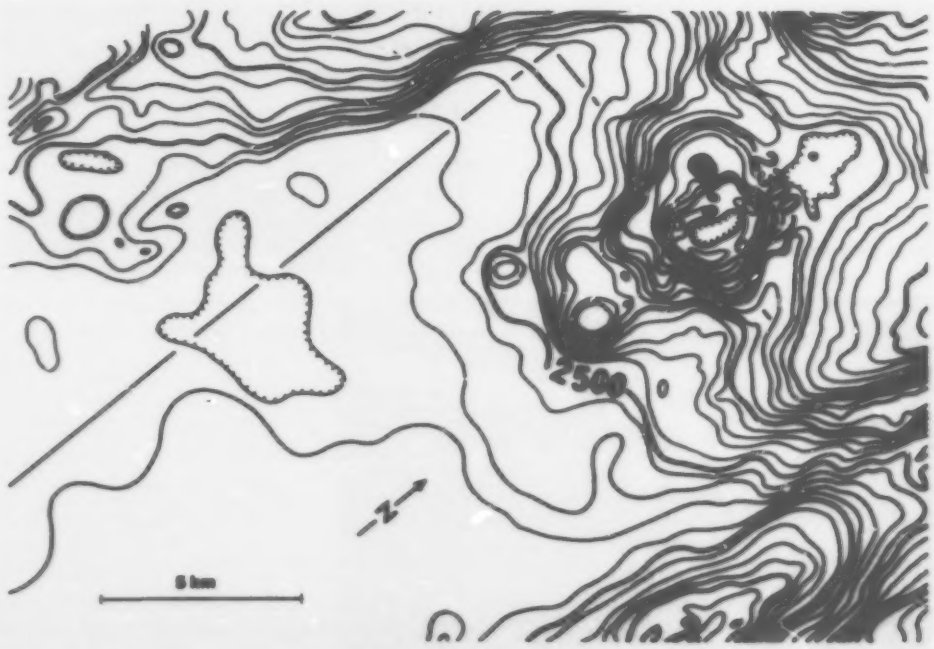

*Composite ship's track showing coverage obtained from 1973 to 1983 inclusive*

The 1983 marine program consisted of a 5-week, multiparameter survey aboard the *CSS Parizeau* during which time 13,500 kilometres of geophysical data were collected. The region covered was south of last year's survey area between the 47th and 49th parallels. Approximately one more field season is required to complete the coverage of the Canadian Economic Zone. One dynamic gravimeter was carried on this cruise, the SL 1, a prototype linear design meter first introduced in 1980. Refinements to this instrument during the last few years, coupled with reasonably good weather during the survey, brought about extremely accurate gravity

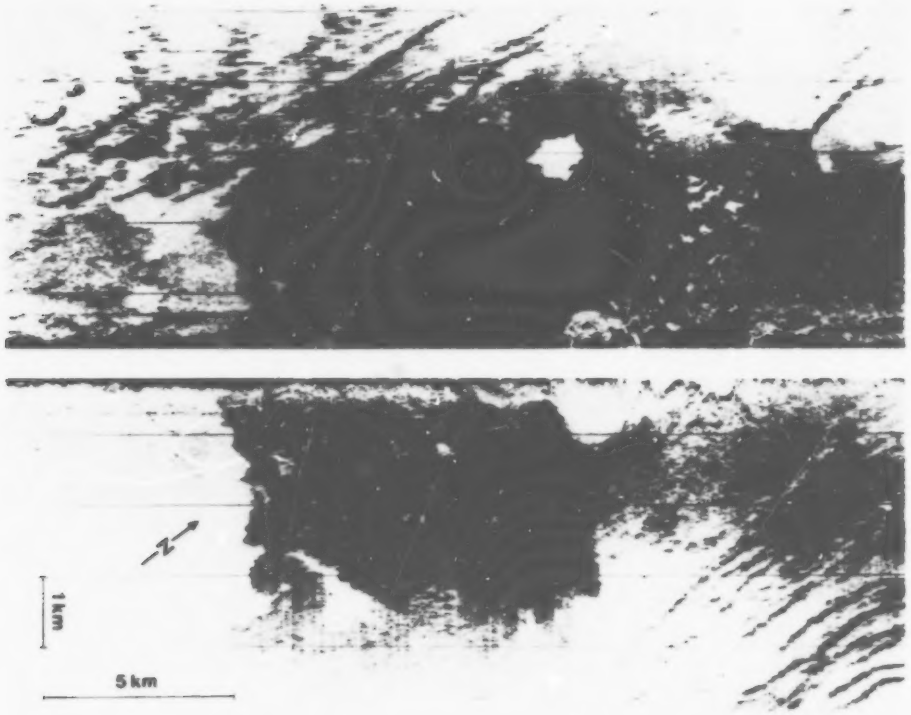
measurements; adjusted trackline intersection values were within ±0.7 mGals (seven parts in 10,000,000 of the earth's gravity). The two test lines, extending 550 km offshore, place limits on the position of the propagating rift trace in this previously unsurveyed portion of the northeast Pacific. *(Contact: R.G. Currie, R.P. Riddihough, D.A. Seemann.)*

## Juan de Fuca Ridge Mapping

New data was collected from the northern Juan de Fuca Ridge system in order to characterize better the tectonic processes and to allow preparation of detailed bathymetric and geological maps. Detailed bathymetric mapping from the NOAA Ship *Surveyor* was carried out in cooperation with National Ocean Surveys using SEABEAM, a multi-beam swath sounding system that produces 10 metre contours over a region that is 2/3 of the water depth under the ship. Maps at a scale of 1:50,000 showing 10 metre contours, were prepared for release in Open File for the Tuzo Wilson Knolls, Explorer Ridge, the Sovanco Ridge and Fracture Zone and the northern Juan de Fuca Ridge.




*SEABEAM bathymetry over the Juan de Fuca Ridge at 48° 15'N, 129° 13'W (20 m contour interval)*




*SeaMARC II side scan image of the same area showing recent volcanism and rifting associated with spreading processes*

SeaMARC II side scan (backscatter and bathymetric) imagery, seismic reflection and 3.5 kHz acoustic profiling data were also obtained from the *R.V. Kana Keoki* of the University of Hawaii working under contract to PGC and CHS. Areas covered were Tuzo Wilson and Dellwood Knolls and the northern Juan de Fuca Ridge. These data afford a new, possibly definitive, look at a spreading ridge. *(Contact: E.E. Davis, R.P. Riddihough, R.G. Currie.)*

## Seismological Service

The Seismological Service provides earth scientists, civil engineers, resource development industries and the public with basic earthquake data, and with research information concerning natural and induced earthquakes, ground motion seismic risk, earth structure, and nuclear explosions. This is accomplished through a network of

seismological stations, including standard and regional stations, two telemetered arrays, strong motion accelerographs and special installations.

*Solar-powered, mountain-top radio telemetered digital seismograph station*

*Recording centre for digital telemetered seismograph network*

## Seismic Networks

The Western Canada Telemetered Network (WCTN), established to provide centralized, on-line monitoring of seismicity in southwestern British Columbia, was expanded in 1983 by two stations. Fourteen stations are now being recorded at the Pacific Geoscience Centre (PGC). *(Contact: D.H. Weichert, G.C. Rogers, M. Bone, A. Whitford, M.J. Gregory.)*

The strong motion seismograph network in western Canada consists of instruments designed to operate and record ground acceleration only when very strong (1/2% of normal gravity or larger) earth motion occurs. During 1983, three new instrument sites in the Queen Charlotte Islands and one site in northern Vancouver Island were added to this network. In addition, commitments involving four private instrument sites were discontinued. The net number of instruments now consists of 35 accelerographs. *(Contact: H. Bennetts, D.H. Weichert.)*

Routine cataloguing of earthquakes in western Canada continued at PGC. Over the first half of 1983, more than 350 earthquakes were located. *(Contact: R.B. Horner.)*

## Special Earthquake Studies

A detailed microearthquake survey was carried out during the summer on the Queen Charlotte Islands in cooperation with the University of British Columbia. Over 250 microearthquakes were recorded, most of them immediately to the west of the Queen Charlotte Islands along the Queen Charlotte fault. Several earthquakes were large enough to be felt by the field party. *(Contact: G.C. Rogers, D.H. Weichert.)*

The expanded telemetered network permitted routine location of microearthquakes within the subducted Juan de Fuca plate 60 to 70 km beneath Georgia Strait and provided the first information on the faulting mechanisms of these deep events. *(Contact: G.C. Rogers.)*

A microearthquake survey was conducted over the IMC potash mine near Esterhazy, Saskatchewan, as part of a joint project with the University of Saskatchewan at Saskatoon to study induced earthquakes. For a period of one week at the end of September, more than 40 microearthquakes were recorded. *(Contact: R.B. Horner.)*

The Beaufort Sea special seismicity study in cooperation with Dome Petroleum was continued through part of the year. The network of five land-based stations is now in reasonable operating condition and should remain in place for another five years. Thoughts about ocean bottom seismometer modifications to allow useful deployment near the seismic cluster are still entertained. *(Contact: D.H. Weichert, G.C. Rogers.)*

## Western Canada Seismicity

During 1983, fourteen earthquakes were reported felt in western Canada. These included three on Vancouver Island, four in southern and eastern B.C., two on the Queen Charlotte Islands, three in the Yukon Territory and one in Saskatchewan. The southwest Yukon earthquake on March 30, magnitude 5.4, and the Queen Charlotte event on April 6, magnitude 5.2, were the two largest earthquakes to occur in western Canada during the year. The most widely felt earthquake was centered in Idaho on October 28. This event, magnitude 7.3, caused considerable damage; there were two deaths near the epicentre, and the earthquake was felt throughout the northwestern United States and western Canada from Saskatchewan to British Columbia. No damage was reported in western Canada for any earthquake in 1983. *(Contact: R.B. Horner, G.C. Rogers, D.H. Weichert.)*

## Seismic Risks

A special study of seismic risk was carried out in 1983 in the Queen Charlotte Sound area. Although the point source model used for the whole of Canada is not appropriate here, the necessary additional assumptions on the unknown statistical distributions of dynamical fault source parameters introduce considerable uncertainty. *(Contact: D.H. Weichert.)*

# Gravity

The principal mandate of the Gravity service is to establish the shape of the geoid in Canada to the highest standards and to determine the value of gravity on a regional basis over the Canadian landmass and offshore areas. The regional gravity data provide information for both the determination of crustal structure and the evaluation of resources and are critical to the operation of inertial navigation systems used by defense agencies for submarines and missiles.

Regional land gravity surveys were continued under contract by McElhanney Surveying and Engineering Ltd. Some 850 new gravity stations were observed in an area of northern B.C. covering approximately 180,000 square kilometres. Stations were positioned predominantly on existing geodetic control, however wellsite information as well as information supplied by local agencies was incorporated to achieve the desired 12 kilometre station spacing.

Further work was carried out this year in the Valemont area where approximately

200 gravity stations from the previous year's survey still required positioning. A Litton-2 helicopter-mounted inertial system was provided by the Geodetic Survey of Canada in order to attain the required ±50 metre horizontal, ±3 metre vertical control.

An in-house gravity survey also was conducted by helicopter in the Willmore Wilderness Park area, Alberta. Since the park is a wildlife refuge, access in the past has proven difficult thereby creating a void in the national coverage.

The marine component of the gravity program is discussed in the "Multi-parameter—Geophysical Surveys" section. *(Contact: R.P. Riddihough, D.A. Seemann, J.F. Sweeney.)*

*Measuring gravity and elevation in Willmore Wilderness Park, Alberta*

## Geothermal Studies

The earth's temperature influences both rock properties and geological processes. Thermal data, particularly surface heat flux, are important indicators of deep tectonic processes and the structure of the earth's crust. Most active tectonic processes that result in mountain building, earthquakes and volcanism originate from thermal energy. Geothermal data also are needed to calculate the degree of maturation of hydrocarbons. In addition, the earth has considerable economic potential as a heat source for geothermal energy.

Measured thermal parameters include surface heat flux (the result of vertical temperature gradient multiplied by the thermal conductivity of the rocks), and heat

production from natural radioactive decay in crustal rocks (for example: thorium, uranium and potassium). Studies cover a wide range of geological and geophysical interests—from heat flow, heat production and thermal processes in the deep sea floor, to the discovery and development of geothermal energy resources in western Canada.

## Land Studies

There is a continuing program to determine the regional geothermal heat flow pattern from borehold measurements in the Canadian Cordillera. These data can be used in the interpretation of regional tectonics and structure, and in the delineation of hot areas with potential for geothermal energy development. Shallow holes were drilled near the Anahim Volcanic Belt west and east of Wells Gray Park. Initial results indicate that the crust has not been extensively heated when the eruptions occur. *(Contact: T. Lewis, W. Bentkowski.)*

A recent paper by Weichert and Hamilton expressed doubts about the Anahim hotspot hypothesis by correlating recent volcanism and earthquake swarm activity in the 1940s in the western part of the Anahim Volcanic Belt.

A study of the heat flux data available in southern British Columbia, defines the Intermontane and Omineca Crystalline Belts as a heat flow province with a very high reduced heat flux of 63 $mWm^{-2}$. The best explanation of the level of heat flow is that it is associated with a back-arc convective heat transfer process in the upper mantle. The Insular Belt and western Coast Plutonic Complex are regions of very low heat flux caused by the subduction of oceanic crust beneath them. The transition from low to high heat flux occurs along Jervis Inlet over a distance of 20 km, as defined by oceanic type measurements in the bottom sediments of the fjord. *(Contact: T. Lewis, W. Bentkowski, E.E. Davis.)*

## Marine Studies

Offshore, geothermal studies focussed first on the hydrothermal regime of the Juan de Fuca Ridge system. The geothermal compilation of the Juan de Fuca plate map was also completed. Secondly, studies focussed on the heat flow and bathymetry of old ocean basins to put constraints on the aging of the oceanic lithosphere. The old Atlantic program is now being followed by a cruise to one of the oldest parts of the Pacific in the Mariana area. Finally, work is continuing on the thermal regime of the ocean crust using measurements in DSDP crustal boreholes. *(Contact: E.E. Davis, H. Villinger, R.D. Hyndman, T. Lewis.)*

# Geomagnetism

## The Geomagnetism Field

The earth's geomagnetic field varies both spatially and temporally. This inherent variability is exploited in a variety of ways. To be utilized for navigation, the magnetic field and its gradual change with time must be determined as a function of latitude and longitude. Changes in the magnetic properties of rocks also lead to spatial variations in the magnetic field which become characteristic signatures of structure, composition, and the thermal history of crustal rocks. Short-period temporal changes in the magnetic field must be monitored in order to resolve subtle spatial field variations as encountered in exploration geophysics.

In Canada, the geomagnetic field is monitored continuously at 13 primary observatory sites and discontinuously at about 140 secondary sites. As part of this Canadian Geomagnetic Network, PGC operates the Victoria Geomagnetic Observatory (VGO) on property near the Dominion Astrophysical Observatory.

PGC also collects magnetic field observations at sites in British Columbia. These data are used in updating maps of the geomagnetic field components for the Canadian land mass every 5 years.

## Geomagnetic Variations

Temporal variations in the earth's magnetic field provide a source of electromagnetic energy with which to probe the earth's electrical conductivity structure. Because of the relationships to other physical properties, electrical conductivity is an important parameter in understanding the active tectonic regions on the west coast. Deep zones of high conductivity, related to high temperatures and partial melting, determine the maximum thickness of the cold lithosphere riding over the asthenosphere. Conductive zones at shallow depths occur in regions with geothermal resource potential.

The analysis of the geomagnetic variation data obtained at three sites across the transform fault west of Queen Charlotte Sound, reveals a complex three dimensional pattern of electric currents in the region. These electric currents flow along the shelf-slope and in the active segments of the spreading ridge in this area.

The injection of electric current into the seafloor via a vertical cable from a ship produces a magnetic field that can be measured with ocean bottom magnetometers. Two profiles, along Princess Royal and Queen's Reach in Jervis Inlet, provided data that determined the conductivity of the bottom sediments. The result from this first

survey proved the feasibility of the method for seafloor conductivity studies. The development of the controlled-source system is a cooperative project involving the University of Toronto, the Geomagnetic Laboratory (E.P.B., Ottawa) and PGC.

Measurements of the electric field on the seafloor have in the past been difficult because of the high noise level of the electrode sensors. With the development of high sensitivity ring-core fluxgate magnetometers, the electric field could be measured as the vertical gradient between two such sensors. A prototype instrument is currently being designed in collaboration with the University of British Columbia. *(Contact: L.K. Law, J.B. DeLaurier, D.R. Auld.)*

## Paleomagnetism

The paleomagnetism of rocks records the variations in directions of the geomagnetic field in the geological past. The intensity of the ancient field is also recorded, but is difficult to observe and can only be obtained in very favourable circumstances. The principal application of paleomagnetism is in tectonics—the study of the motion of continents, the opening and closing of oceans and the origin of mountain belts—but it is also used widely in many problems of stratigraphic correlation, the origins and thermal history of rocks, and in the source and origin of magnetic anomalies.

Paleomagnetic work at PGC is concerned with the tectonics of the Cordillera and the western Arctic and magnetostratigraphic studies. During the last decade, geological and geophysical studies have shown that the Cordillera comprises a number of distinct crustal blocks. Vancouver Island is one such block. Paleomagnetic work has shown that these blocks have been transported from the south by distances over 1000 km; much of central British Columbia once being in the latitude of California or beyond. Indeed, Vancouver Island could have moved northward by over 5000 km relative to North America and may have originated on the other side of the Pacific Ocean. The western Cordillera, therefore, appears to be a collage of small crustal fragments that originated elsewhere, were carried over large distances, and finally glued to North America. This discovery has led to a profound revision of ideas about the origin of this and other mountain belts.

Two major programs were initiated. The objective of the first is to collect a suite for a traverse across the Cordillera from Vancouver Island to the Rockies in order to determine the relative latitudes of the various crustal elements at one geological instant in time; namely the Middle Cretaceous epoch near 100 Ma ago. The second program calls for a traverse across the northern rim of the Sverdrup Basin in Ellesmere Island. Results show an unexpected 30° anticlockwise rotation which may reflect strain distributed across northern Ellesmere Island and may be associated with the opening of Baffin Bay. *(Contact: E. Irving, P.J. Wynne.)*

## Arctic Structure and Tectonics

Re-examination of geophysical data from Canada Basin plus borehole and field mapping information from the adjacent continental margin in Canada, suggest that the basin formed in Early and mid-Cretaceous time. The opening process is tentatively divided into two parts: a continental breakup between about 135 and 110 million years ago, and a seafloor formation phase between about 118 and 79 million years ago. *(Contact: J.F. Sweeney.)*

## Geodynamics

The principal subject of geodynamics study in the active region of the west coast of Canada continues to be contemporary crustal deformation. One main objective of this is to establish realistic dynamic models of crustal plate behavior and utilize these in the study of local earthquakes.

Research in the application of precise gravity measurements in the study of crustal strain continued in two subject areas. In instrumentation research work, an active part was taken in the international calibration campaign for LaCoste and Romberg Model-D gravimeters sponsored by the International Association of Geodesy (IAG). Calibration non-linearities of the Canadian instruments were verified, and these gravimeters can now serve as improved calibration references for other gravimeters. In conjunction with data collection on central Vancouver Island, lake-level monitors have been installed on Buttle Lake to allow *in situ* gravity corrections during the course of the semi-annual precise gravity surveys.

The monitoring of contemporary crustal deformation on central Vancouver Island is also being carried out using vertical and horizontal control surveys. Preliminary relevelling results from 1976 and 1982 indicate an apparent relative uplift of about 3 cm in the Campbell River area. This deformation is not directly reflected in the gravity data and may be, in part, an artifact of magnetic field effects on the compensator of self-levelling instruments.

In a cooperative field project with the Department of Geophysics and Astronomy at U.B.C., an additional two of the original sites of the 1947 triangulation network in the Gold River area were tied into the primary horizontal strain network established in 1982. The added data resulted in a revised regional engineering shear strain estimate of 0.30 ustrain units/a with a compressional axis direction between 10 to 20 degrees east of north.

Preparatory work for the measurement of relative crustal deformation over baselines measuring thousands of kilometres using VLBI (Very Long Baseline Interferometry) was also continued. In preparation for occupation by NASA's mobile

radio antenna, a reference monument and a gravel parking pad were installed at DRAO in Penticton. Local horizontal and vertical control networks for monitoring VLBI site stability were established by the Geodetic Survey of Canada at Whitehorse and Yellowknife. *(Contact: H. Dragert.)*

*Two more horizontal control points were recovered from a triangulation network first established in 1947 in the Gold River area. Using laser-ranging instruments and helicopters to measure temperature and humidity along the line-of-sight, distances between mountaintops as great as 50 km can be measured with an accuracy of 1 to 2 cm.*

# Earth Physics Branch—Technical Support

The technical staff at PGC supported the activities and projects mentioned elsewhere in the PGC review. This included:

The installation of additional seismic telemetry stations at Mt. Grey and Renfrew with a repeater staion at Mt. Lazaar for the Renfrew station, bringing to four the number of stations now deriving their operating power from solar panels and batteries.

Technical staff also participated, in conjunction with the University of Toronto and the Ottawa EPB technical labs, in the development and operation of a "Controlled Source" system and two high-sensitivity Ocean Bottom Magnetometers (OBMs).

The shipboard "Controlled Source" generates known magnetic fields through the application of controlled electric currents between surface and bottom electrical electrodes. The resultant magnetic fields, modified by the earth's crust, are recorded (utilizing solid-state RAM data storage) on the two high-sensitivity OBMs. This system was successfully used on a one-week cruise on *Vector* in October to Jervis Inlet, and is scheduled for additional inlet work in Bute Inlet and in deep-ocean work from *Endeavor* in 1984.

Successful deployment and recovery of the four PGC Ocean Bottom Seismometers (OBS) was achieved off the east coast of Canada. This was a one-month deployment of the instruments on a cooperative project with Atlantic Geoscience Centre utilizing the ship *CFAV Quest*. Three of the OBSs were recovered on schedule, but the fourth unit was recovered, instrument and data intact, several weeks later on the southern coast of Newfoundland. Work continues in the evolution of 'reliable' release system for ocean-bottom packages, mainly in the areas of electro-magnetic and electrolytic release systems.

The computing system used to gather and analyze the seismic digital data from the West Coast Telemetered Network (WCTN) was expanded. A PDP 11/24 has been added to the existing PDP 11/40 and PDP 11/23s to provide redundancy for real-time data acquisition and expanded capability for graphical data analysis.

The Telemetering Heat Probe (from Applied Microsystems Ltd., Sidney, B.C.) for *in situ* temperature gradient and thermal conductivity measurements of oceanic sediments was operated successfully, including use (without telemetry) on the Arctic CESAR project. Additional work is underway to improve the real-time acoustic telemetry of data from the THP to the surface, and in the application of 'outrigger' thermistors to core barrels for deeper-penetration measurements of temperature gradients.

Five IBM PC and two Hyperion microcomputers were acquired. The two portable Hyperion microcomputers will be used for storage and preliminary reduction of field data in geodynamic and marine magnetic programs. The initial uses for the IBM PCs include 'personal' computing (word processing, spreadsheets, etc.) and use as intelligent terminals to various mainframes for transfer and manipulation of program and data files. Future uses may include the acquisition and preliminary analysis of field data. *(Contact: M.N. Bone, H.J. Bennetts, T.C. Bunyan, H.A. Whitford.)*

# APPENDIX I
## Contracts Awarded 1983

*Development of the XBT/XSV Expendable Bathythermograph Deck Unit*
A/D Computing Instruments, Victoria, B.C. $ 10,000

*Development of an Ocean Dumping Control Act*
Edward Anderson Marine Sciences Ltd., Victoria, B.C. ..... 15,000

*Study of the Feeding & Activity Patterns of Marine Zooplankton*
Edward Anderson Marine Sciences Ltd., Victoria, B.C. ..... 12,162

*Preparation of Final Report on Beaufort Sea Zoobenthos Data*
Arctic Labs Ltd., Sidney, B.C. ..... 26,565

*Compilation & Appraisal of Existing Chemical Oceanographic Data from Queen Charlotte Sound, Hecate Strait & Dixon Entrance*
Arctic Laboratories Ltd., Sidney, B.C. ..... 20,568

*Compilation of Existing Chemical Oceanographic Data Sets for the Canadian West Coast Offshore Waters, Georgia Strait, Juan de Fuca Strait, Canada Basin and Arctic Ocean*
Arctic Laboratories Ltd., Sidney, B.C. ..... 53,120

*Survey of Phytoplankton Distribution in the Southern Beaufort Sea: Remote Sensing in Support of Ecological Studies of the Bowhead Whale*
Arctic Laboratories Ltd., Sidney, B.C. ..... 96,500

*Development of Consistent Data Set Rating Scales & Standard Formats for Benthos, Whales, Phytoplankton & Fish*
Arctic Laboratories Ltd., Sidney, B.C. ..... 9,934

*Compilation & Appraisal of Existing Chemical Oceanographic Data from the Queen Charlotte Sound, Hecate Strait & Dixon Entrance Areas*
Arctic Laboratories Ltd., Sidney, B.C. ..... 15,050

*Development of Techniques for Acoustic Measurement of Directional Ocean Wave Spectra*
Arctic Sciences Ltd., Sidney, B.C. ..... 460,000

*Compilation & Appraisal of Existing Physical Oceanographic Data in the Canadian Basin of the Arctic Ocean*
Arctic Sciences Ltd., Sidney, B.C. ..... 39,988

*Design Study for a Seabottom-moored Acoustic Wind Velocity System*
Arctic Sciences Ltd., Sidney, B.C. ..... 30,000

*Study of Geophysical Regions as Potential Sites for a Detailed Investigation of the Flow Past Ice Keels*
Arctic Sciences Ltd., Sidney, B.C. ..... 6,522

*A Study of Current Meter Data Sets for Parry Channel & Adjoining Waterways*
Arctic Sciences Ltd., Sidney, B.C. ..... 12,135

*Study of Echo Sounding from High Speed Hydrographic Launches*
Arctic Sciences Ltd., Sidney, B.C. ..... 8,993

*Modifications of Primitive Equatrous Model to Study Coastal Cyclogenesis*
Atmospheric Dynamics Corp., Victoria, B.C. .... 2,105

*Determination of Optimum Method of Computing Geostrophic Winds in Parry Channel*
Atmospheric Dynamics Corp., Victoria, B.C. .... 5,052

*Study of Severe Storms in the Beaufort Sea for Tuktoyaktuk Flood Delineation Project*
Atmospheric Dynamics Corp., Victoria, B.C. .... 7,578

*Study of Tangential Wind Stress & Atmospheric Pressure Gradients over the Water for the Coast of B.C.*
Atmospheric Dynamics Corp., Victoria, B.C. .... 3,579

*Investigation of Data Quality for Precipitated Chemistry Project*
L. Benson, Brentwood Bay, B.C. ..... 1,350

*Oceanographic Measurement & Analysis of Data on Research Vessel "Charcot"*
G.A. Borstad Ltd., Sidney, B.C. ..... 18,730

*Preparation of an Inventory of Prints & Files of 1979 British Columbia Coastal CZCS Imagery*
G.A. Borstad Ltd., Sidney, B.C. ..... 3,030

*Ship of Opportunity Sampling of the Planktonic Ecosystem off the Pacific Coast of Canada*
Broccoli Bros , Sidney, B.C. ..... 50,323

*Sea Testing of Multiple Net Zooplankton Sampling System*
Broccoli Bros., Sidney, B.C. ..... 8,437

*Analysis of Marine Zooplankton Samples*
Broccoli Bros., Sidney, B.C. ..... 13,645

*A Novel Method of Recovery of Lost Mooring Systems from the Seabed*
Brooke Ocean Technology Ltd., Halifax, N.S. .. 75,000

*Identification, Cataloguing & Disposition of Scientific Collection*
K. Bruce, Sidney, B.C. ..... 11,000

*Testing of Techniques to be Applied to Re-inforcing Photovoltaic Modules for Marine Application*
Cantech Scientific Instruments Ltd.,
North Saanich, B.C. ..... 500

*Numerical Modelling of Shallow Water Kinematic Diffusive Waves on the West Coast of Canada*
CPRO Computing Enterprises, Victoria, B.C. .. 37,697

*Calculation of Extent of Inundation at Tuktoyaktuk Due to Storm Surges*
CPRO Computing Enterprises, Victoria, B.C. ... 5,400

*Development of Irregular Grid Model of Northwest Passage*
CPRO Computing Enterprises, Victoria, B.C. .. 31,544

*Collection of Hydrographic Field Data for Correcting & Updating Navigational Charts, Sailing Directions & Tidal Publications*
Coast Pilot Ltd., Sidney, B.C. ..... 97,535

*Taxonomy of Haplotaxidae*
K. Coates, Saanichton, B.C. ..... 1,995

*Literature Review of Theoretical & Experimental Work on Acoustic Scattering from Turbulence, Microstructure & Biological Targets in the Pacific Ocean*
G. Crawford, Victoria, B.C. ..... 2,500

*Study to Develop the Relationship Between Sound Scattering Temperature and Velocity*
G. Crawford, Victoria, B.C. ..... 2,000

*Study of Metal Binding Proteins in Marine Invertebrates*
Dobrocky Seatech Ltd , North Saanich, B.C. ... 7,374

*Statistical Analysis of Two Large Sediment Data Sets to Provide Minimum Specifications for the Quality Control of Ocean Dumping Analysis*
Dobrocky Seatech Ltd., North Saanich, B.C. ... 14,000

*Development, Construction & Field Testing of Loran-C Tracked Drogues*
Dobrocky Seatech Ltd., North Saanich, B.C. .. 205,391

*Compilation Review & Assessment of Major Environmental Assessment Reports & Atlases for the West Coast of B.C.*
Environmental Sciences Ltd., Vancouver, B.C. . 16,548

*Development of a Discussion Paper on a Method to Initially Evaluate the Environmental Impacts of Proposed Industrial Developments on Marine Mammals & Fish*
Environmental Sciences Ltd., Vancouver, B.C. . 19,984

*Development of Predictive Basis for Mysid & Euphausiid Fishery Utilisation & Management*
E.V.S. Consultants Ltd., North Saanich, B.C. .. 73,865

*Study Effects of Wood Waste on the Recruitment of Marine MacroBenthos*
E.V.S. Consultants Ltd., North Saanich, B.C. .. 15,258

*Development of a Programme of a Finite Difference Shallow Water Model of the Dixon Entrance-Hecate Strait-Queen Charlotte Sound*
M.G. Gatien, Sidney, B.C. ..... 4,800

*Compilation & Correlation of Oceanographic Data in the Lower Fraser River*
A. Hartley, Victoria, B.C. ..... 4,500

*Investigation of Arctic Industrial Offshore Activities & Ocean Dredging & Dumping in B.C. Coastal Waters*
R.H. Herlinveaux, North Saanich, B.C. ..... 10,000

*Technical Review & Oceanographic Assessment of Selected Industrial Proposals*
R.H. Herlinveaux ..... 10,000

*Development of Instrumented Oceanographic Moorings*
A. Hofland, Sidney, B.C. ..... 2,480

*Oceanographic Support for the West Coast of the Queen Charlotte's Survey*
A. Hofland, Sidney, B.C. ..... 2,940

*Computer Programming of a Finite-differential Model of the N.W. Passage*
K. Holtham, Victoria, B.C. ..... 3,248

*Preparation of an Oceanographic Hydrographic Audio-Visual Text for a Department of Fisheries & Oceans Display*
Hoot Productions, Victoria, B.C. ..... 6,500

*Development of Theory & Analysis of Operation of an Echometer for the Remote Detection of Sound*
D. Huston, Sidney, B.C. ..... 3,948

*Development & Evaluation of Methods for Simulating Langrangian Trajectories in Geostrophic Turbulence*
Interact Computing Services Ltd., Sidney, B.C. . 7,840

*Computed Heat Flux Statistics for the North Pacific Based on Transpac XBT Data*
Interact Computing Services Ltd., Sidney, B.C. . 7,810

*Preparation of Charts of Tides & Currents in the Great Barrier Reef of the Coral Sea*
Interact Computing Services Ltd., Sidney, B.C. . 2,458

*Programming of Inverse Method Calculations for Tides in the N.W. Passage*
Interact Computing Services Ltd., Sidney, B.C. 11,167

*Development & Application of Computer Programmes to Process & Analyse Oceanographic Data*
Interact Computing Services Ltd., Sidney, B.C. 20,755

*Parameter Dependence Survey of Large Scale Transport of Tracer Substance by Eddies*
Interact Computing Services Ltd., Sidney, B.C. . 9,597

*Collection & Analyses of Samples from Moored Sediment Trap & Hydrocasts at Ocean Station P*
Iseki Environmental Research,
Central Saanich, B.C. ..... 8,764

*Analysis of Deep Sea Sediment Samples & Report on Analytical Procedures for Deep Sea Particulate Organic Carbon*
ISK Environmental Research,
Central Saanich, B.C. ..... 3,568

*Analysis of Sea Surface Conditions by Long Range Sound Propagation*
Jasco Research Ltd., Victoria, B.C. ..... 6,000

*Design & Deployment of Oceanographic Mooring System off West Coast of Queen Charlotte Islands*
T. Juhasz, Victoria, B.C. ..... 60,375

*Fabrication & Programming of Aanderaa Data Translator*
E. Koome, Victoria, B.C. ..... 5,400

*Compilation & Collation of Tsunami Records*
M. Lane, Victoria, B.C. ..... 3,200

*Data Compilation & Appraisal of Beaufort Sea Whales*
L.G.L. Ltd., Sidney, B.C. ..... 8,855

*Preparation of Detailed Plans to Complete the Development & Testing of the Correlation Sonar Profiling Current Meter*
J.F. Mattock, Edmonton, Alberta ..... 10,000

*Bioaccumulation Studies on Bivalves Exposed to Kitsault Mine Tailings*
D. McLeay & Associates Ltd.,
West Vancouver, B.C. ..... 57,860

*To Modify G & H Series MSI Digitisers*
Meyer Systems Inc., Vancouver, B.C. ..... 20,000

*Preparation of Line Drawings for Scientific Publication*
McSorley Illustration & Design, Victoria, B.C. .. 1,912

*Preparation of an Operational Manual on the Application of Automated Metrolm #636 Titroprocessor to Seawater Samples*
H. Neville, Victoria, B.C. ..... 11,025

*Tsunami Data Computer Programming*
M.M. Nugent, Victoria, B.C. ..... 4,200

*Analysis of Data from FGGE Drifting Buoy Arrays*
Odysseas Ocean Sciences Ltd.,
North Saanich, B.C. ..... 24,975

*Analysis of FGGE Buoy Drifters*
Odysseas Ocean Sciences Ltd.,
North Saanich, B.C. ..... 9,805

*Video Tape Documentation of Sterntow*
Pacific Sea Life Data Inc., Victoria, B.C. ..... 10,000

*Data Interception of Ships of Opportunity*
D. Philip, Vancouver, B.C. ..... 3,150

*Analysis of Tsunami Potential of Landslides*
D. Philip, Victoria, B.C. ..... 2,550

*Investigation of Methods Currently Employed to Obtain Ice Thickness Distribution*
Polar Tech Ltd., North Saanich, B.C. ..... 3,700

*Development of an Electrical Power Generator to Drive Useful Energy from Salinity Gradients through Application of Reverse Electro-Dialysis Techniques*
RETECH—Capital Applied Research & Technology Ltd., Victoria, B.C. ..... 59,990

*Study the Processes Contributing to the Momentum Exchanges between Moving Ice Cover and the Underlying Ocean*
Dr. R.D. Rowe, Calgary, Alberta ..... 19,870

*Oceanographic Data Collection of the Coastal Waters of B.C.*
S & B Research Ltd., North Saanich, B.C. ..... 14,991

*Co-ordination & Interpretation of Precipitation Chemistry Data*
S & B Research Ltd., North Saanich, B.C. ..... 10,304

*Compilation, Processing & Interpretation of Marine Meteorological Data*
S & B Research Ltd., North Saanich, B.C. ..... 10,080

*Analysis of Sea Water Samples*
Seakem Oceanography Ltd., Sidney, B.C. ..... 5,621

*Analysis of Dissolved Nutrients in Sea Water*
Seakem Oceanography Ltd., Sidney, B.C. ..... 8,294

*Analysis of Trace Metals using Ultra Clean Room & Mass Spectrometry*
Seakem Oceanography Ltd., Sidney, B.C. ..... 37,402

*Development, Construction, Test of Correlation Sonar Meter Shipboard & Ocean Bottom Mounted Prototype Systems Phase III & IV*
Seakem Oceanography Ltd., Sidney, B.C. ..... 404,000

*Analysis of Sea Water Samples*
Seakem Oceanography Ltd., Sidney, B.C. ..... 5,621

*Analysis of Marine Air Samples from Land Stations and Other Cruises*
Seakem Oceanography Ltd., Sidney, B.C. ..... 40,000

*Oceanographic Observations Aboard CSS Parizeau*
Soliton, Sidney, B.C. ..... 1,540

*Compilation & Collation of Tsunami Records*
P. Straub, Sidney, B.C. ..... 1,800

*Mobilisation of Equipment & Technical Support for Ocean Turbulence Measurements*
Sy Tech Research Ltd., North Saanich, B.C. ... 4,760

*Documentation of Acoustic System from Coastal Zone Oceanography Field Trials*
Sy Tech Research Ltd., North Saanich, B.C. ... 1,200

*Compile an Inventory List for Engineering Services*
Sy Tech Research Ltd., North Saanich, B.C. ... 2,025

*Design, Fabricate & Test Electronic Circuits for the Echometer Project Phase II*
Sy Tech Research Ltd., North Saanich, B.C. ... 15,540

*Design, Fabricate, Test Electric Circuits*
Sy Tech Research Ltd., North Saanich, B.C. ... 20,607

*Preparation of Draft Diagrams for El Nino Seminar*
I. Szabo, Sidney, B.C. ..... 1,100

*Development of Shallow Water Hydrographic Survey Techniques Using a Fixed Wing Float Plane*
Terra Surveys Ltd., North Saanich, B.C. ..... 42,250

*Seamark II High Resolution Swath Bathymetry & Acoustic Sidescan of Northern Juan de Fuca Ridge System and Vancouver Island Continental Slope*
University of Hawaii, U.S.A. .....390,000

*Numerical Modelling Studies of the Estuarine Circulation in the Strait of Georgia, Part V*
Dr. Burling, University of B.C., Vancouver, B.C. ..... 24,000

*Development of A Fibre Optic Acoustic Detector*
Dr. Branston, University of Victoria, B.C. ..... 12,603

*Develop a "Head Space" Technique to Investigate Air-Sea Transfer of Freon*
Prof. McAuley, University of Victoria, B.C. .... 7,500

*Development of A Remote L/R Indicator for Field Hydrography*
Walker Industrial Computing Ltd., North Saanich, B.C. ..... 5,670

*Development of Scientific Tools for Pisces IV*
Witney, MacInnis Engineering Ltd., Lions Bay, B.C. ..... 64,100

# APPENDIX II
## Publications

### A. Department of Fisheries and Oceans
### (1) Canadian Data Report of Hydrography and Ocean Sciences

| | | |
|---|---|---|
| No. 5 Volume 3 | Birch, J.R., D.B. Fissel, D.D. Lemon, A.B. Cornford, R.A. Lake, B.D. Smiley, R.W. Macdonald and R.H. Herlinveaux | *Arctic Data Compilation and Appraisal. Northwest Passage: Physical Oceanography—Temperature, Salinity Currents and Water Levels* |
| No. 5 Volume 4 | Thomas, D.J., R.W. Macdonald, A.G. Francis, V. Wood and A.B. Cornford | *Arctic Data Compilation and Appraisal. Northwest Passage: Chemical Oceanography* |
| No. 5 Volume 5 | Birch, J.R., D.B. Fissel, D.D. Lemon, A.B. Cornford R.H. Herlinveaux, R.A. Lake and B.D. Smiley | *Arctic Data Compilation and Appraisal. Baffin Bay: Physical Oceanography—Temperature, Salinity, Currents and Water Levels* |
| No. 5 Volume 6 | Fissel, D.B., L. Cuypers, D.D. Lemon, J.R. Birch, A.B. Cornford, R.A. Lake, B.D. Smiley, R.W. Macdonald and R.H. Herlinveaux | *Arctic Data Compilation and Appraisal. Queen Elizabeth Islands: Physical Oceanography— Temperature, Salinity, Currents and Water Levels* |
| No. 7 | Freeland, H.J. | *Low Frequency Currents Observed off Southern Vancouver Island, 1979-1981* |
| No. 8 | Hill, S., K. Denman, D. Mackas, H. Sefton and R. Forbes | *Ocean Ecology Data Report: Coastal Waters off Southwest Vancouver Island. Spring and Summer 1981* |
| No. 9 | Giovando, L.F. | *Observations of Seawater Temperature and Salinity at British Columbia Shore Stations 1980* |
| No. 13 | Giovando, L.F. | *Observations of Seawater Temperature and Salinity at British Columbia Shore Stations 1981* |
| No. 14 | Forbes, J.R., H.A. Sefton and K. de Macedo | *Phytoplankton Productivity Experiments in British Columbia Coastal Waters, 1982 and 1983* |

| | | |
|---|---|---|
| No. 15 | Lee A.Y.P. and D.J. Stucchi | *Alberni Inlet CTD Data Report, 1979-1981* |

## (2) Canadian Technical Report of Hydrography and Ocean Sciences

| | | |
|---|---|---|
| No. 18 | Macdonald, R.W. (ed.) | *Proceedings of a Workshop on the Kitimat Marine Environment* |
| No. 19 | Vermeer, K. | *Marine Bird Populations in the Strait of Georgia: Comparison with the West Coast of Vancouver Island* |
| No. 20 | Melling, H. | *Oceanographic Features of the Beaufort Sea in Early Winter* |
| No. 22 | Kathman, R.D., R.O. Brinkhurst, R.E. Woods and D.C. Jeffries | *Benthic Studies in Alice Arm and Hastings Arm, B.C. in Relation to Mine Tailings Dispersal* |
| No. 25 | Rambold, P.S. and D.J. Stucchi | *An Analysis of the Alice Arm Crash Program Data—Summer 1981* |
| No. 26 | Parker, N. and J. Alexander | *Weather, Ice and Sea Conditions Relative to Arctic Marine Transportation* |
| No. 27 | Melling, H. | *In Situ Determination of the Thermal Diffusivity of Sea Ice* |
| No. 30 | Thomas, D.J., R.W. Macdonald and A.B. Cornford | *A Comparison of Natural and Petroleum Resource-Related Fluxes of Metals, Hydrocarbons and Nitrogen, Phosphorus and Silicon to the Beaufort Sea* |
| No. 31 | Crean, P.B. | *The Development of Rotating, Non-Linear Numerical Models (GF2, GF3) Simulating Barotropic Mixed Tides in a Complex Coastal System Located Between Vancouver Island and the Mainland* |

## (3) Canadian Contractor Report of Hydrography and Ocean Sciences

| | | |
|---|---|---|
| No. 8 | Ford, L. and M. Nicoll | *Oceanographic Observations in Alice Arm, B.C., May 1981* |
| No. 9 Volume I | Greisman, P. | *Physical Oceanography of Bridport Inlet, N.W.T. Analysis and Interpretation* |
| No. 9 Volume II | Greisman, P. | *Physical Oceanography of Bridport Inlet, N.W.T. Individual CTD Casts* |

| | | |
|---|---|---|
| No. 11 | Woods, S.M. and S.C. Byers (eds.) | *Report on Ocean Dumping R&D Pacific Region, Department of Fisheries and Oceans 1981-1982* |
| No. 14 | May, G.A. | *Correlation Sonar Using Pseudo-Random Noise Codes* |

## (4) Other Publications, 1983


BAKER, H.R. 1982. To new Phallodriline genera of marine Oligochaeta (Annelida; Tubificidae) from the Pacific northeast. *Can. J. Zool.*, **60**: 2487-2500.

BAKER, H.R. 1982. *Vadicola aprostatus* nov. gen. nov. spec., a marine oligochaete (Tubificidae; Rhyacodrilinae) from British Columbia. *Can. J. Zool.*, **60**:3232-3236.

BAKER, H.R. 1983. New species of *Tubificoides* Lastockin (Oligochaeta; Tubificidae) from the Pacific northeast and the Arctic. *Can. J. Zool.*, **61**: 1270-1283.

BAKER, H.R. 1983. New species of *Bathydrilus* Cook (Oligochaeta; Tubificidae) from British Columbia. *Can. J. Zool.*, **61**: 2162-2167.

BELL, W.H. 1983. Turbulence vs drag—some further considerations. *Ocean Engineering*, Vol. 10(1): 47-63.

BENNETT, A.F. 1983. The South Pacific including the East Australian Current. In: *Eddies in Marine Science*, A.R. Robinson (ed.), Springer-Verlag, 219-344.

BENNETT, A.F. and L.M. LESLIE. Statistical correction of dynamical prognoses: the decision problem. *Monthly Weather Review, 111:* 344-352.

BENNETT, A.F. and D.B. HAIDVOGEL. 1983. Low-resolution numerical simulation of decaying two-dimensional turbulence. *Journal of the Atmospheric Sciences*, **40**: 738-747.

BENNETT, A.F. and K.J.F. MIDDLETON. 1983. Statistical mechanics of a finite-difference approximation to the barotropic vorticity equation. *Quarterly Journal, Royal Meteorological Society*, 109.

BENNETT, A.F. 1983. Predictability and frontogenesis. In: *Predictability of Fluid Motions*, G. Holloway and B.J. West (eds.), American Institute of Physics, New York.

BRINKHURST, R.O. 1983. Coastal ecology: an essay on practical approaches in coastal zone management in British Columbia, B. Sadler (ed.). *Cornett Occasional Papers*, **3**: 53-64.

BRINKHURST, R.O. 1983. Book review of *Coastal Research in the Gulf of Bothnia. Can. J. Fish. Aquat. Sci.*, **39**: 253.

BRINKHURST, R.O., P.M. CHAPMAN and M.A. FARRELL. 1983. A comparative study of respiration rates of some aquatic oligochaetes in relation to sublethal stress. *Int. Rev. ges. Hydrobiol.*, **68**: 683-699.

BRINKHURST, R.O. and R.D. KATHMAN. 1983. A contribution to the taxonomy of the Naididae (Oligochaeta) of North America. *Can. J. Zool.*, **61**.

BRINKHURST, R.O. and R.D. KATHMAN. 1983. *Varichaetadrilus*, a new name for *Varichaeta* Brinkhurst, 1981 *non* Speiser, 1903 (Diptera) with a description of a new species *V. fulleri*. *Proc. Biol. Soc. Wash.* **96**: 301-306.

BRINKHURST, R.O. and R.D. KATHMAN. 1983. *Arctodrilus wulikensis* new genus new species (Oligochaeta; Tubificidae) from Alaska. *Proc. Biol. Soc., Wash.* **96**: 407-410.

CARNEVALE, G.F. and G. HOLLOWAY. 1982. Information decay and the predictability of turbulent flows. *Journal of Fluid Mechanics*, **116**: 115-121.

CLIFFORD, S.F. and D.M. FARMER. 1983. Ocean flow measurements using acoustic scintillation. *J. Acoust. Soc. Am.*, **74**(6): 1826-1832.

CORNFORD, A.B. and R.W. MACDONALD. 1983. Scientific evaluation of marine disposal of False Creek sediments pertinent to the Ocean Dumping Act and the Fisheries Act, 15 pp.

COSSON, R.P. and J.A.J. THOMPSON. 1983. Utilisation de l'électrode PAR 303 pour la détection et le dosage des métallothionéines dans les tissus d'invertebrés marins. *Analusis*, **11**: 33-35.

CRAWFORD, W.R., R.E. THOMSON and W.S. HUGGETT. 1983. Continental shelf waves of diurnal period along Vancouver Island. In: *Coastal Oceanography*, H. Gade, A. Edwards and H. Svendsen (eds.), Plenum Press, 225-234.

CRAWFORD, W.R. 1983. Energy flux and generation of shelf waves along Vancouver Island. *J. Phys. Oceanogr.*

CREAN, P.B., M. BOLTON, W.S. HUGGETT. *Atlas of Currents: Juan de Fuca Strait and Strait of Georgia*. Canadian Hydrographic Service, Department of Fisheries and Oceans, Ottawa.

CREAN, P.B. 1983. A numerical approach to simulating the estuarine circulation in a strongly tidal deep coastal sea between Vancouver Island and the mainland. In: *Proceedings of the 3rd International Conference on Applied Mathematical Modelling*, Mitteilungen Des Institut für Meereskunde der Universitat Hamburg, No. 26.

CRETNEY, W.J., C.S. WONG, R.W. MACDONALD, P.E. ERICKSON and B.R. FOWLER. 1983. Polycyclic aromatic hydrocarbons in surface sediments and age dated cores from Kitimat Arm, Douglas Channel and adjoining waterways. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 162-196.

DENHARTOG, G., S.D. SMITH, R.J. ANDERSON, D.R. TOPHAM and R.G. PERKIN. 1983. An investigation of a polynya in the Canadian archipelago. III, Surface heat flux. *J. Geo. Res.*, **88** (C5).

DENMAN, K.L. 1983. Predictability of the marine planktonic ecosystem. In: *Predictability of Fluid Motions*, G. Holloway and B.J. West (eds.), Am. Institute of Physics, New York, 570-572.

DENMAN, K.L. and A.E. GARGETT. 1983. Time and space scales of vertical mixing and advection of phytoplankton in the upper ocean. *Limnology and Oceanography*, **28**: 801-815.

DWORSKI, J.G. and G. HOLLOWAY. 1983. Statistical representations of seafloor topography. *Univ. of Washington, Special Report* No. **94**.

ERSEUS, C. and H.R. BAKER. 1982. New species of the gutless marine genus *Inanidrilus* (Oligochaeta; Tubificidae) from the Gulf of Mexico and Barbados. *Can. J. Zool.*, **60**: 3063-3067.

FARMER, D.M. and H.J. FREELAND. 1983. The physical oceanography of fjords. *Progress in Oceanography*, **12**(2): 147-220.

FARMER, D.M. and G.B. CRAWFORD 1983. Measurements of acoustic correlation in the ocean with a high frequency echo-sounder. *Nature*, **301**, No. 5902, 698-700.

FARMER, D.M. Stratified flow over sills. 1983. In: *Coastal Oceanography*, H. Gade, A. Edwards and H. Svenden (eds.), Plenum Press, 337-362.

FARROW, G.E., J.P. SYVITSKI and V. TUNNICLIFFE. 1983. Suspended particulate loading on the macrobenthos in a highly turbid fjord, Knight Inlet, B.C. *Can. J. Fish. Aquat. Sci.*, **40**: 273-288.

FILLMORE, S. and R.W. SANDILANDS. *The Chartmakers—A History of Nautical Surveying in Canada*, NC Press, Toronto, 255 pp.

FOREMAN, M.G.G. 1983. An analysis of two-step time discretizations in the solution of the linearized shallow water equations. *Journal of Computational Physics*, Vol. 51, No. 3, 454-483.

FOREMAN, M.G.G. An analysis of the wave equation model for finite element tidal computations. *Journal of Computational Physics*, Vol. 52, No. 1, 290-312.

FREELAND, H.J. 1983. A seasonal upwelling event observed off the west coast of British Columbia, Canada. In: *Coastal Oceanography*, H. Gade, A. Edwards and H. Svenden (eds.), Plenum Press, N.Y., 217-223.

FREELAND, H.J. 1983. Book review of *Descriptive Physical Oceanography* by Pickard and Emery. *Can. J. Fish. Aquat. Sci.*, **40**(3): 385.

FREELAND, H.J., W.R. CRAWFORD and R.E. THOMSON. 1983. Currents along the Pacific coast of Canada. *Atmosphere-Ocean*. In press.

GOWER, J.F.R. 1983. "Layover" in satellite radar images of ocean waves. *J. Geophys. Res.*, **88**: 7719-7720.

GOWER, J.F.R. 1983. Water colour imaging from space. Paper presented at the *15th International Liege Colloquium on Ocean Hydrodynamics*, May 1983.

HAIDVOGEL, D.B. and G. HOLLOWAY. 1983. Predictability: Lagrangian and Eulerian views. In: *Predictability of Fluid Motions*, Amer. Inst. of Physics, 67-68.

HOLLOWAY, G. 1982. On interaction time scales for oceanic internal waves. *J. Physical Oceanography*, **12**: 293-296.

HOLLOWAY, G. 1982. Theories of the oceanic internal wave environment. *Technical Report PD-NW-80-244R. Physical Dynamics Inc.*, Bellevue, Washington, 83 pp.

HOLLOWAY, G. 1982. A comment on streakiness. *Ocean Modelling*, No. 43.

HOLLOWAY, G. 1983. Effects of planetary wave propagation and finite depth on the predictability of atmospheres. *J. Atmos. Sci.*, **40**: 314-327.

HOLLOWAY, G. 1983. A conjecture relating oceanic internal waves and small scale processes. *Atmos-Ocean*, **21**: 107-122.

HOLLOWAY, G. 1983. Contribute to: *Dispersal from Ocean Sources: Physical and Related Scientific Processes*, A.R. Robinson and S.L. Kupferman (eds.), *Sandia National Laboratory Report*, to appear, 212 pp.

HOLLOWAY, G. and B.J. WEST. (Eds.). (c1983) *Predictability of Fluid Motions*. Amer. Inst. of Physics, 604 pp.

HOLLOWAY, G. 1983. Contrary roles of planetary wave propagation in atmospheric predictability. In: *Predictability of Fluid Motions*, 593-600.

HUGGETT, W.S. and S.O. WIGEN. 1983. Surface currents in the approaches to Kitimat. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 34-64.

HUGHES, B.A. and J.F.R. GOWER. 1983. SAR imagery and surface truth comparisons of internal waves in Georgia Strait, British Columbia, Canada. *J. Geophys. Res.*, **88**: 1809-1824.

JOHNSON, W.K. and C.S. WONG. 1983. Manual for mercury analysis of sea water at Ocean Chemistry Division. *Ocean Chem. Project Rep.*, 29 pp.

LEVINGS, C.D., R.E. FOREMAN and V. TUNNICLIFFE. 1983. Review of the benthos of the Strait of Georgia and contiguous fjords. *Can. J. Fish. Aquat. Sci.*, **40**: 1120-1141.

LEWIS, E.L. and R.G. PERKIN. 1983. Supercooling and energy exchange near the Arctic Ocean surface. *J. Geophys. Res.*, **88**(C12): 7681-7685.

LIN, S., G.A. BORSTAD and J.F.R. GOWER. 1983. Remote sensing of chlorophyll in the red spectral region. Paper presented at the *15th International Liege Colloquium on Ocean Hydrodynamics*, May 1983.

LITHERLAND, J. and G. HOLLOWAY. Statistical theory of the predictability of equivalent barotropic motion on a beta plane. In: *Predictability of Fluid Motions*, 333-348.

LUECK, R.G., W.R. CRAWFORD and T.R. OSBORN. 1983. Turbulent dissipation over the continental slope off Vancouver Island. *J. Phys. Oceanogr.* In press.

MACDONALD, R.W., D.M. MACDONALD and C.S. WONG. 1983. Manual for the determination of Pb-210 at Ocean Chemistry Division. *Ocean Chem. Project Rep.*, 29 pp.

MACDONALD, R.W., M. O'BRIEN, D.M. MACDONALD and V. SCOTT. 1983. A manual for the determination of particulates in sea water by filtration at Ocean Chemistry, 11 pp.

MACDONALD, R.W., B.D. BORNHOLD and I. WEBSTER. 1983. The Kitimat fjord system, an introduction. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 2-14.

MACDONALD, R.W., W.J. CRETNEY, C.S. WONG and P. ERICKSON. 1983. Chemical characteristics and water in the Kitimat fjord system. *Can. Tech. Rep. Hydrogr. Oc. Sci.:* **18**, 66-88.

MACDONALD, R.W. 1983. The distribution and dynamics of suspended particles in the Kitimat fjord system. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 116-138.

MACDONALD, R.W. and D.J. THOMAS. 1983. Assessing environmentally acceptable levels of metals in drilling products: The Beaufort Sea as a case study. In: *Proceedings of the 12th Annual Arctic Environmental Workshop, Issues of the 80s*, 137-156.

MURTY, T.S. Boundary integral solutions for water wave problems. *Journal of Hydraulic Engineering*, Amer. Soc. of Civil Engineers, Vol. 109, No. 6, 939-940.

MURTY, T.S. and R.F. HENRY. Tides in the Bay of Bengal. *J. Geophys. Res.*, **88**(C10): 6069-6076.

MURTY, T.S., G.A. MCBEAN and B. MCKEE. Explosive cyclogenesis over the northeast Pacific Ocean. *Monthl Weather Review*, Vol. III, No. 5, 1131-1135.

MURTY, T.S. Sunspot activity and tsunamis in the Pacific Ocean. *Lighthouse*, No. 27, 31-32.

MURTY, T.S. Meteorology and oceanography in the Falkland Islands region. *Lighthouse*, No. 26, 10-13.

MURTY, T.S. Storm surges and tsunamis on the coastlines of Canada. In: *Proceedings of the Canadian Coastal Conference—83*, Vancouver, B.J. Holden (ed.), published by the Associate Committee for Research on Shoreline Erosion and Sedimentation, N.R.C., Ottawa, 135-148.

MURTY, T.S. Book review of *Identification of Seismic Sources—Earthquake or Underground Explosion*, E.S. Husebye and S.Mykkeltveit (eds.), D. Reidel Publishing Co., Dordrecht. In: *Marine Geodesy*, Vol. 6, Nos. 3-4, 343-344.

MURTY, T.S. Book review of *Current Research in Earthquake Prediction*, T. Riktake (ed.), D. Reidel Publishing Co. Tokyo. In: *Marine Geodesy*, Vol. 6, Nos. 3-4, 345-346.

MURTY, T.S. Book review of *The Sea Floor: An Introduction To Marine Geology*, by E. Seibold and W.H. Berger, Springer-Verlag, Berlin. In: *Marine Geodesy*, Vol. 6, Nos. 3-4, p. 353.

ORTNER, P.B., R.E. PIEPER and D.L. MACKAS. 1983. Advances in zooplankton sampling. In: *Report on Fish Ecology III—A Foundation for a Recruitment Experiment*, B. Rothschild and C. Rooth (eds.), University of Miami Press, 355-380.

SANDILANDS, R.W. 1983. Vignettes from hydrography's past. In: *Proc. Centennial Conf. Canadian Hydrographic Service 1983*, Ottawa, April 5-8, 1983. Can. Special Publication of Fisheries and Aquatic Sciences 67, 36-41.

SANDILANDS, R.W. Hydrographic surveying in the Great Lakes during the nineteenth century. *International Hydrographic Review*, Monaco, LX(2), July 1983. (Reprinted from the Canadian Surveyor.)

SEKI, H., F.A. WHITNEY and C.S. WONG. 1983. Copper effects on dynamics of organic materials in marine controlled ecosystems. *Arch. Hydrobio.*, **96**: 176-189.

SHEN, C. and G. HOLLOWAY. 1982. Spectral formulation of internal wave interaction. *Technical Report No. 392, School of Oceanography, University of Washington*, 36 pp.

SMITH, S.D , R.J. ANDERSON, G. DENHARTOG, D.R. TOPHAM and R.G. PERKIN. An investigation of a polynya in the Canadian archipelago—II, Structure of turbulence and sensible heat flux. *J. Geo. Res.*, **88**(C5).

STUCCHI, D.J. 1983. Shelf-fjord exchange on the west coast of Vancouver Island. In: *Coastal Oceanography*, H. Gade, A. Edwards and H. Svenden (eds.), NATO Conf. Ser., Marine Sciences Ser. IV, Plenum Press, 439-450.

STUCCHI, D.J. and L.F. GIOVANDO. 1983. Deep water renewal in Saanich Inlet, B.C. In: *Oceanography of an Intermittently Anoxic Fjord*, S.K. Juniper and R.O. Brinkhurst (eds.). In press.

STUKAS, V.J. and C.S. WONG. 1983. Accurate and precise analysis of trace levels of Cu, Cd, Pb, Zn, Fe and Ni in sea water by isotope dilution mass spectrometry. In: *Trace Metals in Sea Water*, C.S. Wong *et al* (eds.), Plenum Press, N.Y., 513-536.

STUKAS, V.J. and C.S. WONG. 1983. Application of isotope dilution mass spectrometry to the determination of Cu, Cd, Pb, Zn, Fe and Cr in sea water. *Marine Chemistry*, **12**: 133-146.

TABATA, S. 1983. Interannual variability in the abiotic environment of the Bering Sea and the Gulf of Alaska. In: *"From Year to Year", Interannual Variability of the Environment and Fisheries of the Gulf of Alaska and the Eastern Bering Sea*, W.S. Wooster (ed.), A Washington Sea Grant Publication, University of Washington, 139-145.

TABATA, S. 1983. Accuracy of NOAA-7 observed SST in the northeast Pacific Ocean. Presented at *Jet Propulsion Lab., Cal. Inst. Tech.*, 9 pp.

TABATA, S. 1983. Oceanographic conditions off the Pacific coast of Canada during the 1982-1983 El Nino. Presented at the *8th Climate Diagnostic Workshop*. (NOAA and AES), 22 pp.

TABATA, S. 1983. Influence of ocean conditions on the production of salmonids. Presented at the *Cooperative Institute for Marine Resource Studies, Oregon State University*, 50 pp.

THOMSON, R.E. 1983. A comparison between computed and measured oceanic winds near the British Columbia coast. *J. Geophys. Res.*, **88**: 2675-2683.

THOMSON, R.E. 1983. Physical oceanographic aspects of coastal British Columbia. In: *Coastal Zone Management in British Columbia*, Barry Sadler (ed.), *Cornett Occasional Papers*, No. 3, 7-27.

THOMSON, R.E. Book review of *Hydrodynamic Instabilities, and the Transition to Turbulence*, H.L. Swinney, and J.P. Gollub (eds.), Springer-Verlag, Berlin. In: *Marine Geodesy*, Vol. 6, No. 2, 190 pp.

THOMSON, R.E. 1983. El Nino: An equitorial phenomenon of global importance. Presented at *DFO Field Services Branch Annual Meeting*, November, 1983.

TOPHAM, D.R., R.G. PERKIN, S.D. SMITH, R.J. ANDERSON and G. DENHARTOG. An investigation of a polynya in the Canadian archipelago — I, Introduction and oceanography. *J. Geophys. Res.*, **88**(C5).

TUNNICLIFFE, V., R.L. CHASE, G.E. FARROW and D. NELSON. 1983. Rocks, sediments and benthos of Cobb Seamount, northeast Pacific Ocean. *Geol. Assoc. Can.*, Abstr. v. 8, p. A70.

TUNNICLIFFE, V. and J.P. SYVITSKI. 1983. Corals move boulders: an unusual mechanism of sediment transport. *Limnol. Oceanogr.*, **28**: 564-568.

WOLANSKI, E. and A.F. BENNETT. Continental shelf waves and their influence on the circulation around the Great Barrier Reef. *Australian Journal of Marine and Freshwater Research*. **34**: 23-47.

WOLANSKI, E. and R.E. THOMSON. 1983. Wind-driven circulation on the northern Great Barrier Reef continental shelf in summer. *J. Estuarine Coast. Marine Sci.* In press.

WONG, C.S., E.A. BOYLE, K.W. BRULAND, J.D. BURTON and E.D. GOLDBERG (eds.). 1983. *Trace Metals in Sea Water. Proceedings of a NATO Advanced Research Institute* held in Erice, Italy, March 30 - April 5, 1983, Plenum Press, N.Y., 891 pp.

WONG, C.S., K. KREMLING, J.P. RILEY, W.K. JOHNSON, V. STUKAS, P.G. BERRANG, P. ERICKSON, D. THOMAS, H. PETERSON and B. IMBER. 1983. Intercomparison of sampling devices and analytical techniques using sea water from a CEPEX enclosure. In: *Trace Metals in Sea Water*, C.S. Wong *et al* (eds.), Plenum Press, N.Y., 175-193.

## B. Department of the Environment

MCBEAN, G.A. Boundary layer structure over the ocean. Paper presented at *CMOS Conference*, Banff, Alberta, May 1983.

MCBEAN, G.A. Precipitation chemistry in Pacific coastal regions. Paper presented at *CMOS Conference*, Banff, Alberta, May 1983.

VERMEER, K., I. ROBERTSON, R.W. CAMPBELL, G. KAISER and M. LEMON. 1983. Distribution and densities of marine birds on the Canadian west coast. *Can. Wildlife Serv. Report*, Vancouver, B.C., 73 pp.

VERMEER, K. 1983. Comparison of the diet of the Glaucous-winged Gull on the east and west coasts of Vancouver Island. *Murrelet*, **63**: 80-85.

VERMEER, K. 1983. Diet of the Harlequin Duck in the Strait of Georgia, British Columbia. *Murrelet*, **64**: 54-57.

## C. Department of Energy, Mines and Resources


BECKER, M., H. DRAGERT, E. KANNGIESER, A. LAMBERT, J. MAKINEN, B. RICHTER and D. WOODWARD. 1983. Report on High-Precision Gravimetry—Volume II. *Report to IAG by Special Study Group 3.37*, E. Groton (ed.), *Informations on Cartography and Geodesy. Series II; Translations, No. 41, Institut für Angewandte Geodesie, Frankfurt A.M.*

BENTKOWSKI, W.H. and T.J. LEWIS. 1983. Preliminary results of shallow drilling in the Garibaldi Volcanic Belt, British Columbia, 1982. *Earth Physics Branch Open File Report 83-23*, 38 pp.

BORNHOLD, B.D. 1983. Detailed textural analyses of Miocene to Quarternary sediments, Leg 71. *Init. Rep. Deep Sea Drilling Project*, **71**: 1183-84.

BORNHOLD, B.D. 1983. Sedimentation in Douglas Channel and Kitimat Arm. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 88-114.

BORNHOLD, B.D. 1983. Geological processes in fjords. *Geos.*, **12**: 1-4.

BORNHOLD, B.D. 1983. Ice-rafted debris in sediments from Leg 71, southwest Atlantic Ocean. *Init. Rep. Deep Sea Drilling Project*, **71**: 307-316.

CLAGUE, J.J., J.L. LUTERNAUER and R.J. HEBDA. 1983. Sedimentary environments and postglacial history of the Fraser Delta and lower Fraser Valley, British Columbia. *Can. J. Earth Sci.*, **20**:1314-1326.

CURRIE, R.G. and B.D. BORNHOLD. 1983. The magnetic susceptibility of shelf sediments, west coast Vancouver Island. *Mar. Geol.*, **51**: 115-127.

CURRIE, R.G., R. COOPER, R.P. RIDDIHOUGH and D.A. SEEMANN. 1983. Multi-parameter geophysical surveys off the west coast of Canada, 1973-1982. *GSC Paper 83-1A*: 207-217.

DALY, L. and E. IRVING. 1983. Paléomagnetisme des roches carboniféres du Sahara central; analyse des aimantation juxtaposées; configuration de la Pangée. *Annales Geophysical*, **1**: 207-216.

DRAGERT, H. 1983. Evaluation of the GDD Electronic Level for relative lake-height measurements. *PGC Internal Report 83-1.*

DRURY, M.J. and T.G. LEWIS. 1983. Water movements within Lac Dubonnet Batholith as revealed by detailed thermal studies of three closely-spaced boreholes. *Tectonophys.*, **95**: 337-351.

ELLIS, R.M., G.D. SPENCE, R.M. CLOWES, D.A. WALDRON, I.F. JONES, A.G. GREEN, D.A. FORSYTH, J.A. MAIR, M.J. BERRY, R.F. MEREU, E.R. KANASEWICH, G.L. CUMMING, Z. HAJNAL, R.D. HYNDMAN, G.A. MCMECHAN and B.D. LONCAREVIC. 1983. The Vancouver Island Seismic Project: a CO-CRUST onshore-offshore study of a convergent margin. *Can. J. Earth Sci.*, **20**: 719-741.

HAMILTON, T.S. and J.L. LUTERNAUER. 1983. Evidence of sea floor instability in the south-central Strait of Georgia, B.C.—a preliminary compilation. In: *Current Research, Part A; GSC Paper 83-1A:* 417-421.

HERZER, R.H. and B.D. BORNHOLD. 1982. Glaciation and post-glacial history of the continental shelf off southwestern Vancouver Island, British Columbia. *Mar. Geol.*, **48**: 285-319.

HORNER, R.B. 1983. Seismicity in the St. Elias region of northwestern Canada and southeastern Alaska. *Bull. Seism. Soc. Am.*, **73**: 1117-1137, Contr. 1056.

HORNER, R.B. 1983. Earthquakes in Saskatchewan: a potential hazard to the potash industry. In: *Potash Technology*, R.M. McKurcher (ed.), *Proceedings of the 1st International Potash Technology Conf., Oct. 3-5, 1983, Saskatoon, Sask.*, 185-190, Contr. 1078.

HYNDMAN, R.D. and D.H. WEICHERT. 1983. Seismicity and rates of relative motion on the plate boundaries of western North America. *Geophys. Jour. R. Astr. Soc.*, **72**: 59-82.

IRVING, E. and J.F. SWEENEY. 1982. Origin of the Arctic Basin. *Trans. R. Soc. Can.*, **20**: 407-416.

JOHNSON, H.P., J.L. KARSTEN, J.R. DELANEY, E.E. DAVIS, R.G. CURRIE and R.L. CHASE. 1983. A detailed study of the Cobb Offset of the Juan de Fuca Ridge: evolution of a propagating rift. *Jour. Geop. Res.*, **88**, 33: 2297-2315.

LEWIS, T. 1983. Bottom water temperature variations as observed, and as recorded in the bottom sediments, Alice Arm and Douglas Channel, British Columbia. *Can. Tech. Rep. Hydrogr. Oc. Sci.*, **18**: 138-161.

LUDWIG, W.J., V. KRASHENINNIKON *et al.* 1983. Sites 511, 512, 513, 514. *Init. Rep. Deep Sea Drilling Project*, **71**: 21-109.

LUTERNAUER, J.L., J.J. CLAGUE and C. PHARO. 1983. Substrates of the Strait of Georgia. *Can. J. Fish. Aquat. Sci.*, **40**: 1026-1032.

LUTERNAUER, J.L. and W.D.L. FINN. 1983. Stability of the Fraser River Delta Front. *Can. Geotechnical Jour.*, B: 20 pp.

NELSON, C.S. and B.D. BORNHOLD. 1983. Temperate skeletal carbonate sediments on Scott Shelf, northwestern Vancouver Island, Canada. *Mar. Geol.*, **52**: 241-266.

PICKRILL, R.A. and R.G. CURRIE. 1983. Computer programs to estimate wave generated orbital velocities and threshold erosion velocities. *GSC Paper 83-1A:* 253-261.

PRIOR, D.B., B.D. BORNHOLD and J.M. COLEMAN. 1983. Geomorphology of a submarine landslide, Kitimat Arm, British Columbia. *GSC Open File.*

PRIOR, D.B., J.M. COLEMAN and B.D. BORNHOLD. 1983. Results of a known sea-floor instability event. *GeoMarine Letters*, **2**: 117-122.

RIDDIHOUGH, R.P., M.E. BECK, R.L. CHASE, E.E. DAVIS, R.D. HYNDMAN, S.H. JOHNSON and G.C. ROGERS. 1983. Geodynamics of the Juan de Fuca Plate. In: *Geodynamics of the Eastern Pacific Region, Caribbean and Scotia Arcs*, R. Cabre (ed.), *Geodynamic Series of the American Geophysical Union, Washington, D.C.*, **9**: 5-21.

ROBERTSON, P.B. and J.F. SWEENEY. 1983. The Haughton impact structure: structural and morphological aspects. *Can. J. Earth. Sci.*, **20**: 1134-1151, Contr. 1041.

ROGERS, G.C. 1983. Some comments on the seismicity of the northern Puget Sound—southern Vancouver Island region. In: *Earthquake Hazards of the Puget Sound Region, Washington State*, J.C. Yount and R.S. Crosson (eds.), *USGS Open File Report, 1983-19, Menlo Park, Ca.*: 19-39.

ROGERS, G.C. and J.C. SOUTHER. 1983. Hotspots trace plate movements. *Geos.*, **12**: 10-13.

SUTHERLAND BROWN, A., C.J. YORATH and H.W. TIPPER. 1983. Geology and tectonic history of the Queen Charlotte Islands. *Geol. Assoc. Canada, Field Guide Book.*

SWEENEY, J.F. 1983. Evidence for the origin of the Canada Basin margin by rifting in Early Cretaceous time. In: *The Origin of the Arctic Ocean (Canada Basin)*, G.C. Mull and K.M. Reed (eds.), *J. Alaska Geol. Soc.*, **2**: 17-23, Contr. 1040.

SWEENEY, J.F. 1983. Arctic-Alaska, a two-stage displaced terrane. *Eos*, Trans. Am. Geophys. Union, **64**: 87, 1983.

WEICHERT, D.H., G.C. ROGERS, R.H. HYNDMAN and K.B. HORNER. 1983. Seismic risk of the Queen Charlotte Islands and adjacent area. *Proc. of the 4th Can. Conf. Earthquake Engin., Vancouver, B.C.*

WETMILLER, R.J., R.B. HORNER, A.E. STEVENS and G.C. ROGERS. 1983. *Canadian Earthquakes—1980.* Seismological Series of the Earth Physics Branch, Ottawa, No. 87, 60 pp.

YORATH, C.J. and B.E.B. CAMERON. 1982. Oil off the west coast? *Geos.*, **11, 2**: 13-15.

YORATH, C.J. and R.D. HYNDMAN. 1983. Subsidence and thermal history of Queen Charlotte Basin. *Can. J. Earth. Sci.*, **20**: 135-159.

# APPENDIX III

## Permanent Staff 1983
## Institute of Ocean Sciences

### A. Department of Fisheries and Oceans

#### Director-General

Mann, C.R.; B.Sc., M.Sc. (N.Z.), Ph.D. (Brit. Col.), D.Eng. (N.S. Tech.), FRSC
Van Dusen, T.S.

#### Management Services Division

*Chief of Division:*
Todd, N.A.; B.Sc. (Glasgow), M.A. (Carleton)

Adamson, G.
* Clapp, L.A.
Coldwell, J.H.
Cooper. B.J.
Curtis, J.N.
* Deane, G.J.
Denney, C.E.
Doxey, K.
Drysdale, A.E.
Firth, C.
Grills, C.J.
Hope, T.
Keding, L.M.
Kroeger, K.
Lafortune, A.J.; B.A. (Manitoba)
Lapp, B.I.; B.A. (Victoria)
Lohrmann, B.A.; B.Sc., M.Sc. (Guelph)
** MacMillan, B.
* McKee, C.
Oakfield, C.L.
Perras, P.M.
Sabourin, J.T.
Smith, K.R.
Thomson, L.S.C.; B.A. (Sask), B.L.S. (B.C.)
Tillie, D.G.
Van Eyk, W.J.

**Commissionaires**

* Sgt. W.L. Caldwell
Sgt. D.W. Price
** Sgt. N. Hull
Comm. L. Trerice
Comm. H. Moffat
Comm. J. Holliger
Comm. B. Ashton
Comm. F. Alexander
Comm. L. Moe
Comm. R. Morris
Comm. W. Wilson
Comm. L. Brown
Comm. M. Brundrige
** Comm. E. Hill

* Left in 1983
** Joined in 1983

# Personnel

*Regional Personnel Manager:*

Hamilton, K.R.; B.A. (Brit. Col.)

** Groves, L.D.; Dip. (Victoria)
Knapp, B.M.
* McGregor, D.A.; B.A. (Victoria)
Olauson, E.J.
Smith, S.C.
Stevens, I.B.; CIMA (McMaster)
Trentelmann, E.

* Left in 1983
** Joined in 1983

# Hydrography

*Director of Hydrography:*
Bolton, M.; C.L.S.

Ages, A.B.; B.A.Sc., M.A.Sc. (Brit. Col.), P.Eng.
Bell, R.D.
Browning, P.C.
Canning, B.
Chapeskie, R.
Coldham, F.A.
Collins, T.
Crawford, W.R.; B.Sc., M.A.Sc. (Waterloo), Ph.D. (Brit. Col.)
Crowley, J.V.; C.L.S.
Crowther, W.S.; CC (Ont. Inst. of Chartered Cartographers)
Curran, T.A.; B.A.Sc. (EE), M.Sc. (Brit. Col.), P.Eng.
Czotter, K.L.; Dip. BCIT
Dobson, D.C.
Dorosh, L.W.; Dip. BCIT
Douglas, A.; B.Sc. (Victoria)
Earl, E.L.P.
Eaton, G.H.; Dip. BCIT, B.Sc. (UNB)
Ellison, G.
Farmer, P.M.
Fisher, D.L.
Galloway, J.L.; B.A.Sc, (EE), M.A.Sc. (EE) (Brit. Col.), P.Eng.
Gould, J.
Halcro, K., Dip. BCIT
Hare, R.; Dip. BCIT
Harrison, D.W.
Hartung, W.
Hermiston, F.V.
Hinds, E.W.; Dip. BCIT
Hohl, M.
Hollinger, C.; Dip. BCIT
Holman, K.R.
Huggett, W.S.; Master (FG), C.L.S.
Jackson, D.
Jennings, M.
Johnson, B.A.; Dip. BCIT
Kenny, B.
Kidson, G.
Korhonen, R.K.
Larkin, J.B ; B.Sc. (PEI)
Lee, K.S.
Loschiavo, R.; Dip. BCIT
Lusk, B.C.; Master (350 T), C.L.S.
Lyn[illegible]berg, K.; Dip. BCIT
Lyon, A.G.
Ma, A.C.; B.Sc. (Victoria)
** McGregor, B.G.; Dip. BCIT
Michaux, S.D.
Milner, P.R.; Dip. BCIT
Moody, A.E.
Mortimer, A.R.; Master (FG), B.Sc. (Victoria) C.L.S.
Muse, R.A.; Trade Cert. CAF
Nowak, C.; Dip. BCIT
Osborne, M.
Parks, J.R.; B.A.Sc. (EE) (Brit. Col.)
Patton, M.M.
Pfluger, H.
Philp, A.R.
Pickell, L.M.
Pierce, R.A.
Pite, H.
Popejoy, R.D.
Rapatz, W.J.; B.Sc. (Victoria), C.L.S.

Raymond, A.R.; Dip. (Algonquin College)
Redman, D.
Richardson, G.E.; C.L.S.
Roberts, J.W.; Master (FG), Cdr. RCN (Ret'd.)
Ross, A.D.; CC (Ont. Inst. of Chartered Cartographers)
Sandilands, R.W.; Lt. (H) RN (Ret'd.), C.L.S., FRGS
Sargent, E.D.; Dip. BCIT
Schofield, A.
Smedley, A.J.; LCdr. RCN (Ret'd.)
Smith, A.; Master (FG)
Smith, G.R.; B.A.Sc. (ME) (Brit. Col.), P.Eng.
Steeples, J.; Cert. Mech. Eng. (Edinburgh)
Stephenson, F.E.; B.Sc. (Victoria)
Taylor, R.G.
Taylor, W.R.; Dip. BCIT
Tennant, M.
Thompson, L.G.
Thomson, A.D.; Dip. BCIT
Tuck, B.
Van Duin, W.P.; Dip. BCIT
Vosburgh, J.A.; Dip. BCIT, C.L.S.
Wakefield, L.M.
Ward, M.M.; Dip. BCIT, B.A. (Lakehead)
* Wardle, P.
Watt, B.M.
Whincup, G.
Wigen, S.O.; B.A.Sc. (Brit. Col.), P.Eng.
*** Woods, M.V.; Dip. BCIT
Woodward, M.J.; B.C. (Victoria), M.Sc. (Toronto)
Woollard, A.; B.Sc. (Victoria)
Woolley, R.; Dip. BCIT
Yee, J.

* Left in 1983
** Joined in 1983
*** Educational Leave

## Ship Division

*Regional Marine Superintendent:*

Parkinson, R.W.; Engineer 1st Class;
Member, Institute of Marine Engineers

Fitch, L.A.H.; Master H.T.;
Assist. Marine Superintendent
Smith, F.V.; Depot Supervisor
Doyle, D.A.; Secretary
Craton, M.; Administration Clerk

CSS *PARIZEAU*

Chamberlain, A.G.; Master F.G., Master
Butler, K.; Master F.G., 1st Officer
Downey, R.; ON II, 2nd Officer
Gimbel, K.; W.K.M.; 3rd Officer
Pereira, P.B.; Engineer 1st Class Combined, Chief Engineer
Tran, K.H.; Engineer 2nd Class Motor, Senior 2nd Engineer
Stanway, J.D.; Engineer 3rd Class Motor, 2nd Engineer
Miller, S.; Engineer 4th Class Motor, 3rd Engineer
Purdie, D.; Engineer 4th Class Motor, 4th Engineer
Palmer, S.; Supply Officer
Smith, J.R.
Clark, L.E.
Maple, E.J.
Waterfall, J.P.
Springett, B.R.
Hogan, J.
McKechnie, D.G.
Laforest, B.G.
Stokes, J.J.
Waistell, G.A.
Smart, T.R.

CSS *VECTOR*

MacKenzie, R.W.; Master H.T., Master
Wheeler, M.G.; Master H.T., 1st Officer
Campbell, J.; Mate H.T., 2nd Officer
Pearson, R.; Engineer 3rd Class Motor, Chief Engineer
Burrell, R.; Engineer 3rd Class Motor, 2nd Engineer
MacQuarrie, I.C.; Engineer 4th Class Motor, 3rd Engineer
Burns, R.G.
White, R.M.
Anderson, D.D.
Lavigne, R.
Robie, D.J.
Kirby, D.B.

CSS *RICHARDSON*

Coombes, A.; ON I, Master
Campbell, J.; Watchkeeping Mate, Master
Osip, W.J.; Engineer 4th Class Motor, Chief Engineer
Beebe, E.; Engineer 4th Class Motor, Chief Engineer
Temple, D.
Knoblauch, D.

*PISCES IV*

Chambers, F.J.; Chief Pilot
Taylor, R.H.; Pilot
Witcombe, A.; Pilot
Oszust, J.; Pilot
Shepherd, K.; Pilot
Holland, R.; Pilot

*DECK MACHINERY*

Bradbury, J.D.

*SHORE PARTY and RELIEF POOL*

Newton, B.L.; Master F.G.
Allison, G.R.
Sanderson, R.L.
Gurney, J.P.
Lovelace, R.S.

M.V. *PANDORA II* (Charter)

Gulati, S.; Master
Rogers, R.; Chief Engineer

## Ocean Information

*Chief of Division*
Cornford, A.B.; B.Sc. (McMaster), Ph.D. (Brit. Col.)

Giovando, L.F.; B.A., M.A., Ph.D. (Brit. Col.)
Glover, K.T.; B.A. (UNB)
* Peirson, E.
** Pitcher, J.A.
Smiley, B.D.; B.Sc., M.Sc. (Alberta)

* Left in 1983
** Joined in 1983

## Ocean Chemistry Division

*Chief of Division:*
Wong, C.S.; B.Sc., M.Sc. (Hong Kong), Ph.D. (Scripps),
Dip. Mar. Sc. (UNESCO), F.R.S.Chem. (U.K.), F.C.I.C.

Bellegay, R.D.; Dip NAIT, Assoc. Deg. in Oceanography
(Shoreline Community College, Seattle)
Cretney, W.J.; B.Sc., Ph.D. (Brit. Col.)
Johnson, W.K.; Dip. BCIT
Macdonald, D.M.; B.A.Sc. (Brit. Col.)
Macdonald, R.W.; B.Sc., Ph.D. (Dalhousie)
McLaughlin, F.A.; B.Sc. (Victoria)
O'Brian, M.C.; B.Sc. (Alberta)
Paton, D.W.; B.Sc. (Brit. Col.)
Poulin, J.G.
Smith, G.L.; Dip. NAIT
Soutar, T.J.; Dip. BCIT
Thompson, J.A.J.; B.Sc. (McMaster) Ph.D. (Alberta), F.C.I.C.
Whitney, F.A.; B.Sc. (Brit. Col.)

## Ocean Physics Division

*Chief of Division:*

Garrett, J.F.; B.A. (Harvard), Ph.D. (Brit. Col.)

Bell, W.H.; B.A.Sc. (Brit. Col.), M.Sc. (Hawaii), P.Eng.
Bennett, A.F.; B.Sc. (U. of Western Australia), M.S., Ph.D. (Harvard)
Bigham, R.W.
** Budgell, W.P.; B.A.Sc. (Waterloo), M.Eng. (McMaster), Ph.D. (Waterloo)
Chase, G.W.; Dip. BCIT
Cooke, R.A.; Dip. RCC
Crean, P.B.; B.Sc. (Dublin), M.A.Sc. (Toronto), Ph.D. (Liverpool)
de Jong, C.
Delacretaz, A.
Farmer, D.M.; B.Comm., M.Sc. (McGill), Ph.D. (Brit. Col.)
Francis, D.B.; B.Sc. (Victoria)
Freeland, H.J.; B.A. (Essex), Ph.D. (Dalhousie)
Gargett, A.E.; B.Sc. (Manitoba), Ph.D. (Brit. Col.)
Gower, J.F.R.; B.A., M.A., Ph.D. (Cantab)
Henry, R.F.; B.Sc. (Edinburgh), Ph.D. (Cantab)
Holloway, G.; B.A., M.S., Ph.D. (California)
Johnston, P.
Kamitakahara, G.R.; B.Sc. (Toronto)
Koppel, A.W.
Kimber, P.M.
Kuwahara, L.S.C.; B.Sc. (Brit. Col.)
Lake, R.A.; B.Sc. (Brit. Col.). M.Sc. (Washington)
Lee, A.Y.P.; B.Sc. (Victoria)
Lewis, E.L.; B.Sc., M.Sc., Ph.D. (London)
Love, J.
Mathias, A.L.
Meikle, J.H.
Melling, H.; B.Sc., M.Sc., Ph.D. (Toronto)
Minkley, B.G.; Dip. BCIT
Miyake, M.; B.S. (EE) (Drexel), M.S., Ph.D. (Washington)
Moonie, J.A.
Moorehouse, S.W.
Murty, T.S.; B.Sc., M.Sc. (Andhra), M.S., Ph.D. (Chicago)
Perkin, R.G.; B.A.Sc., M.Sc. (Brit Col.)
Quay, L.
Richards, D.L.
Spearing, L.A.F.; B.Sc. (Brit. Col.)
Stickland, J.A.
Stucchi, D.J.; B.A.Sc. (York), M.Sc. (Dalhousie)
Sudar, R.B.; B.A.Sc. (Toronto)
Tabata, S.; B.A., M.A. (Brit. Col.), D.Sc. (Tokyo)
Teichrob, R.C.; Dip. BCIT
Thomson, R.E.; B.Sc., Ph.D. (Brit. Col.)
Topham, D.R.; D.L.C., D.C.A.E., Ph.D. (Loughborough)
Wallace, J.S.

** Joined in 1983

## Computing Services

*Head:*

Teng, K.; B.A.Sc., M.A. (Brit. Col.)

Douglas, A.N.; B.Sc. (Victoria)
Foreman, M.G.; B.Sc. (Queen's), M.Sc. (Victoria)
Green, J.W.; B.Sc. (Victoria)
Johns, R.E.; B.Sc. (Victoria), M.Sc. (Brit. Col.)
Lee, D.K.; B.S. (Chosun-Korea), M.S. (Oregon)
Lee, K.S.; B.Sc. (Victoria)
Linguanti, J.; B.Sc. (Victoria)
Ma, A.C.; B.Sc. (Victoria)
Oraas, S.R.; B.A.Sc., M.A.Sc. (Brit. Col.)
Page, J.S.; B.Sc. (Brit. Col.)
Smith, L.J.; B.Sc. (Simon Fraser)
Woollard, A.L.; B.Sc. (Victoria)

## Ocean Ecology Division

*Chief of Division:*
Brinkhurst, R.O.; B.Sc., Ph.D., D.Sc. (London)

Denman, K.L.; B.Sc. (Calgary), Ph.D. (Brit. Col.)
Forbes, J.R.; B.Sc. (Carleton), M.Sc. (Alberta)
Hill, S.H.; B.Sc. (Brit. Col.), M.Sc. (Victoria)
Mackas, D.L.; B.S., M.S. (Washington), Ph.D. (Dalhousie)
** Moore, D.F.; B.Sc. (McMaster)
Stone, M.

** Joined in 1983

# B. Department of the Environment

## Atmospheric Environment Service

McBean, G.A.; B.Sc. (Brit. Col.), M.Sc. (McGill), Ph.D. (Brit. Col.)

## Canadian Wildlife Service

Vermeer, K.; M.Sc. (Brit. Col.), Ph.D. (Alberta)

# C. Department of Energy, Mines and Resources

## Pacific Geoscience Centre

*Director:*
Hyndman, R.D.; B.A.Sc., M.A.Sc. (Brit. Col)., Ph.D. (A.N.U.)

*Head, Marine Geology (GSC):*
Yorath, C.J.; B.Sc. (Brit. Col.), M.Sc. (Alberta), Ph.D. (Queen's)

*Chief Scientist, Pacific Geophysics Division (EPB):*
Law, L.K.; B.A.Sc. (Toronto), M.Sc. (U. of Western Ontario), Ph.D. (Cantab)

## Administrative Group

Fyfe, K.; Head
Chisholm, D.M.
McDonald, L.J.
** Meeres, M.
Price, W.
* Studsrud, W.A.L.

## Technical Support Groups

### Geological Survey of Canada:

Forbes, T.; B.Sc. (Simon Fraser)
Frydecky, I.I.; B.A.Sc., M.A.Sc. (Brit. Col.), P. Eng.
Hill, W.; (BCIT)
Jewsbury, G.C.; B.Sc. (Victoria)
Johns, M.; B.Sc. (Brit. Col.)

### Earth Physics Branch:

Bone, M.N.; Head, B.A.Sc. (Toronto)
Bennetts, H.J.
** Bowker, D.
Bunyan, T.C.
Whitford, H.A.

## Marine Geology and Geophysics Subdivision

Bornhold, B.D.; B.Sc. (Waterloo), M.A. (Duke), Ph.D. (M.I.T. — Wood's Hole)
Cameron, B.E.B.; B.Sc., M.Sc. (Alberta), P.Geol.
Currie, R.G.; B.Sc., M.Sc. (Brit. Col.)
Hamilton, T.; B.Sc. (Case Western Reserve), A.M. (Indiana), Ph.D. (Alberta)
Luternauer, J.L.; B.A. (Colby), M.A. (Duke), Ph.D. (Brit. Col.)
McLaren, P.; B.Sc., M.Sc. (Calgary), Ph.D. (South Carolina)
Yorath, C.J.; B.Sc. (Brit. Col.), M.Sc. (Alberta), Ph.D. (Queen's)

## Pacific Geophysics Division

### Seismology Section

Weichert, D.H.; Head, B.A.Sc., M.Sc., Ph.D. (Brit. Col.)
Davis, E.E.; B.Sc. (U.C., Santa Barbara),
Ph.D. (U. of Washington)
Gregory, M.J.
Horner, R.; B.Sc. (Manitoba)
Hyndman, R.D.; B.A.Sc., M.A.Sc. (Brit. Col.),
Ph.D. (A.N.U.)
Rogers, G.C.; B.Sc. (Brit. Col.), M.Sc. (U. of Hawaii),
Ph.D. (Brit. Col.)

### Geomagnetic Section

Law, L.K.; Head, B.A.Sc. (Toronto), M.Sc. (U. of Western
Ontario), Ph.D. (Cantab)
Auld, D.R.; B.A.Sc. (Brit. Col.)
DeLaurier, J.M.; B.Sc. (Queen's)
Irving, E.; M.A., Sc.D. (Cantab), D.Sc. (Hon. Carleton),
FRSC, FRS.
Wynne, P.J.; B.Sc. (Queen's), M.Sc. (Memorial)

## Gravity, Geothermics and Geodynamics Section

Riddihough, R.P.; Head, B.Sc. (Kings College, London),
DIC, M.Sc. (Imperial College, London), Ph.D. (U. of London)
Bentkowski, W.; B.Sc. (U. of Western Ontario)
Dragert, H.; B.Sc. (Toronto), M.Sc., Ph.D. (Brit. Col.)
Lewis, T.J.; B.A.Sc., M.Sc. (Brit. Col.), Ph.D. (U. of Western Ontario)
Seemann, D.; B.Sc. (Brit. Col.)
Sweeney, J.F.; B.A., M.A., Ph.D. (S.U.N.Y., Buffalo)

*Left in 1983
**Joined in 1983

# Organization Chart

## Pacific Marine Sciences and Oceans